STRUCTURE OF A PRIMATE COMMUNITY IN RESERVE ADOLPHO DUCKE, CENTRAL AMAZONIA

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Statement of originality

This is to certify that the content of this thesis is my own work. Any assistance from sources have been cited and acknowledged.

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Equations

[1] $$\widehat{D} = \frac{n}{a}$$

[2] $$\hat{p} = \frac{\int_0^w \hat{g}(x)dx}{g(0) \times w} = \frac{\hat{\mu}}{g(0) \times w}$$

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Abstract

Primate surveys that aim to determine the structure of a local community and the population densities of its constituent species are essential when assessing the conservation status of primates. Such information is important to inform conservation actions and management plans. However, for many areas in the Amazon, the primate community structure is entirely unknown. This dissertation will present research on the density, group size and distribution of primates at Reserve Adolpho Ducke in Central Amazon, Brazil. The reserve is located north of Manaus and it is the most important and renowned research site in the Amazon basin. It covers an area of 10,000 hectares of primary rainforest bordering the city of Manaus. Line transect sampling was used to survey the primates with a total of 248km walked between February – May 2018. Nine transects were sampled resulting in 108 sightings of 5 different species including 16 *Saguinus bicolor*, 44 *Sapajus apella*, 14 *Alouatta macconnelli*, 18 *Pithecia chrysocephala*, and 11 *Chiropotes sagulatus*. All densities were estimated using DISTANCE software. The most common species with the highest density was *A. macconnelli* (3.16 group/km2) followed by *S. apella* (2.76), *P. chrysocephala* (1.29), *S. bicolor* (1.05) and *C. sagulatus* (0.88). This study shows that the reserve has a high density of primates throughout, despite being surrounded by the large metropolitan region of Manaus. However, due to the reserve's proximity to Manaus, it is at high risk of hunting, urban expansion and deforestation and invasive species such as domestic cats and dogs. Ongoing studies in this area are essential for the future protection of the reserve.

Finally, this study explored, how the new frontier of arboreal camera trap technology can be used to survey primates. Eleven camera traps were situated in the canopy for 91 days between January - April 2018 capturing 11,643 images and videos. 261 of these files had images and videos of detections recording five out of six primate species, Kinkajou (*Potos flavus*), Ingrid Squirell, (*Sciuus ingrami*) and three bird species. Results from this study have proposed solutions to common problems associated with arboreal camera traps. This study suggests that more cameras are required to understand the full extent of arboreal life at Reserve Adolpho Ducke but findings from this study suggest that camera traps are an essential tool when surveying primates in tropical forest ecosystems.

Abbreviations

RFAD – Forest Reserve Adolpho Ducke

MFTZ – Manaus Free Trade Zone

BNDFF - Biological Dynamics of Forest Fragments Project

INPA – National Institute of Amazon Research

PPBio – Research Program on Biodiversity

RAPELD - RAP stands for Rapid Assessments Program, and PELD is the acronym for long term ecological research in Portuguese

NP – National Park

IUCN - World Conservation Union

ICMBIO - Chico Mendes Institute for Biodiversity Conservation

IMBAMA – Brazilian Institute of Environment and Renewable Natural Resources

Definitions

Urbanisation – The shift of populations and people from rural areas to urban areas and cities

Anthropogenic – Direct or indirect disturbances to ecosystems from human interference or development.

Statement of the Problem

Obtaining accurate population density estimates is crucial when assessing primate conservation status (Defler and Pintor, 1985). In many areas of the Amazon, primate densities are generally unknown. Distance-sampling (Buckland et al., 2011) has become the most popular method used to survey wildlife (Gilhooly, Rayadin and Cheyne, 2015). This method has been consistently and successfully used in primate surveys and long-term monitoring studies (Wallace, Painter and Taber, 1998). Due to the duty-free status given to Manaus municipality in 1967, the human population has increased six-fold reaching the current 2 million people (Gordo et al. 2013). This has caused an unprecedented urban expansion with great loss of surrounding primary forests. In this study, we carried out survey of primate populations in Reserve Florestal Adolpho Ducke (RFAD), located on the northern border of the city of Manaus. Our objective was to provide the status of primate populations in the reserve at the time and to compare them with previous studies.

1. Introduction

Natural ecosystems are being destroyed and depleted worldwide due to the increase of anthropogenic disturbances (Owusu, Ofori and Attuquayefio, 2018). Most of the remaining tropical forest ecosystems can be found in countries with a growing economy and extensive population growth, likely to drive destruction, deforestation and fragmentation. Primates play an essential ecological role in their respective ecosystems serving as seed dispersers and pollinators (Brodie, 2018; Ruiz-Garcia and Shostell, 2016). Furthermore, primates are a vital role in maintaining forest structure as 80% of Amazonian tree species depend on primates for seed dispersal (Iturri and Howe, 2007). The Amazon rainforest is one of the most diverse ecosystems in the world with a high endemism of primates (Da Silva, Rylands and da Fonseca, 2005). Despite this, countless primate populations are declining throughout the Amazon (Almeida-Rocha, Peres and Oliveira, 2017). The latest edition of the world's 25 most endangered primates 2016-18 state that land conversion into pastures, deforestation, hunting and government initiatives are the main threat to primates throughout the neotropics (Schitzer et al., 2016). In addition, our lack of knowledge of many primate population distributions has led to deficiencies in data throughout the Amazon.

1.1.Amazonian primates

The Brazilian Amazon inhabits a large diversity of primates with a total of 133 different species (Primate-sg, 2019). This number is continuously changing and 13 new species have been discovered in Brazil since 1990 (Sciencedaily, 2002). These new species discoveries can be explained by Alfred Russel wallaces' riverine hypothesis (Wallace, 1852). It suggests that extensive river network in the amazon basin has reduced gene flow of populations on opposite sides of the rivers (Boubli, 2008). Biogeography studies focusing on genetic and biogeographic research also highlights the diversification throughout the neotropics (Alfero et al., 2015). Furthermore, geographical factors effect primate densities as highlighted in Emmons (1984), whereby floodplains and terra firme forests differ in primate species and promotes diversity and sympatric overlap (Freese et al., 1982**;** Pontes, 2008).

Primate communities are highly diverse throughout the Amazon basin. Some areas in the amazon hold 13-14 sympatric primate species such as Tefe National forest. However, some areas are impoverished and only have 3-6 sympatric species which includes Reserve Adolpho Ducke (RFAD) which has 6 primate species (Pontes, 1998). These differences in diversity can be due to historical and environmental factors which also includes soil fertility and habitat structure (Peres, 1999). Soil fertility will effect food availability which will also effect primate abundance and diversity (Pontes, Paula and Magnusson, 2012; Pontes, 1998).

1.2. Threats to Central Amazonian primates

Brazil is facing its own environmental crisis due to the government pursuing mass development which includes hydro-electric dam development, farming initiatives and infrastructure development (Morton et al, 2006; Meyer et al., 2017; Gollnow and Lakes, 2014). In addition, funding is being cut for many environmental projects with government funding being the lowest in Brazilian history (Magnusson et al., 2018). Detrimentally leading to the population decline of 63 primate species in the Amazon (Estrada et al., 2017).

1.2.1 Deforestation

Government incentives to improve the economy led Brazil to have a large deforestation rate of tropical forest averaging 19,500 km2/year from 1996 to 2005 (Nepstad et al., 2010), but recently this deforestation has increased sharply (INPE, 2019). This increase is due to the current government attitudes towards environmental issues which is promoting large scale agriculture, urban expansion and infrastructure development (Morton et al., 2006).

Destruction is more intense in the Southern Amazon particularly in the states of Mato Grosso, Rondonia and Para. These states have been the target for agriculture expansion due to the nutrient rich land and easy road access (Fearnside, 2005). The state of Amazonas is currently sheltered from these developments as it can only be accessed by boat and air which has resulted in 70% of untouched forest (Bolaños, 2011). The majority of deforestation in the

Amazonas region has mainly occurred around the metropolis of Manaus and along the Amazon river. However, planned infrastructure and the agenda of the current government this could rapidly change in the next ten years.

1.2.2 Hunting

Hunting was made illegal in Brazil in 1967 with an exception for sustenance hunting. Subsistence hunting is a common throughout rural communities and indigenous tribes as an essential food source (Francesconi et al., 2018). Regardless, the scale of hunting in the Amazon has gradually increased over the last ten years due to accessibility into once-isolated forests primarily due to human disturbance (Peres, 2009). It is having a detrimental effect on large mammal densities with hunted areas having 20% less vertebrate biomass than that of a non-hunted area (Jerozolimski and Peres, 2003). In addition, the density of human populations correlates with hunting throughout the neotropics (Wilkie et al., 2011) which proposes that urbanisation close to tropical forests is a more significant threat to large mammals than initially suspected (Parry, Barlow and Pereira, 2014).

Primates are vulnerable to hunting due to their slow life history including long interbirth intervals, parental investment and small litter sizes (Peres, 1999). In the Amazon, Ateline primates (*Ateles* spp) are more vulnerable and favourable to hunters due to their large body mass (Peres, 1997). The genus Alouatta are also vulnerable as they hide rather than flee when detected by humans (Aquino et al., 2016). Although, medium sized species such as capuchins and sakis are still harvested at rapid rates in areas were larger species are absent (Hill, 1996). Smaller species such as Saguinus are less affected by hunting due to being less desirable to hunters and a faster interbirth interval (Rosin and Swamy, 2013). As more humans live in close proximity to once isolate areas of the Amazon, it is likely to believe primate populations are going to be effected by hunting.

1.2.3 Urbanization of Manaus

Urbanisation is defined as the movement of people from rural to city areas (Bicca-Marquez, 2017) or the development of rural land for urban use (Champion, 2001). Urbanisation is becoming a severe problem to pristine forests causing habitat loss, an increase in hunting and depletion of wildlife populations (Scheun et al., 2015). Primates are directly affected by urbanisation from pollution, infrastructure (cable lines and road killings), food restriction and human conflict (Gordo et al. 2013).

Urbanisation and human expansion are increasing around Manaus, the capital city of the Amazonas state due to it becoming the fastest growing urban area in Central Amazonas (Padoch et al., 2008). The Amazonas region has been considered "urbanised" since the 1980s but up until recently has had little effect on local wildlife and forests with 70% of forest still untouched. The history of this region can provide insight into why urbanisation which is causing deforestation is becoming a serious issue.

The Manaus free trade zone (MFTZ) was implemented in 1967 due to poverty and low economic development in the region (Costa and Brondizo, 2009). This zone allowed for the development of industry to grow into international markets (Castilho, 2018). This zone is now responsible for 90% of income generated in the state of Amazonas (Gordo et al., 2013). The MFTZ is indirectly affecting the environment around the Manaus due to unorganised growth and destruction which has led to loss of local biodiversity which is likely to continue as the MFTZ has been extended until 2073.

1.3 Census Importance

Only 16% of all publications to date represent neotropical primates, with 9% based in Brazil. This statistic is comparatively low to research produced on African and Asian primates (McLennan, Spagnoletti and Hockings, 2017). Nevertheless, neotropical primates are just as diverse in behavior and ecology than their old world counterparts, which is often seen in their complex social systems which can be monogamous, multi-male/female and polyandrous (Strier, 1990; Ruiz-Garcia and Shostell, 2016). The lack of representation of neotropical primate has led to the deficiency of population estimates throughout the Amazonian rainforest (Palacios and Peres, 2005). Therefore, census strategies are important to undertake and prioritise in conservation action plans, in order to gain a better understanding of the current state of neotropical primates.

Primate census sampling in tropical ecosystems is generally conducted using distance sampling techniques specifically line transect sampling (Thomas et al., 2010). Line transect sampling has been a proven method when estimating the density of primates, however, as primates in the neotropics (Platyrrhine) are specially adapted to arboreal habitats (Marsh and Chapman, 2013), sampling them using land-based survey methods can be challenging due to dense vegetation and forest inaccessibility. These difficulties may lead to the violation of assumptions set by the method (Buckland, 2011), which can lead to biased density estimates.

In the last ten years, new sampling techniques have facilitated exciting and reliable new ways of collecting data on cryptic and arboreal species. Innovative methods are now utilised to study the canopies of rainforests from drones to camera trap technology. Camera traps have rarely been used to monitor mammals in the canopy in the Brazilian Amazon, and only three studies have been published exploring this in South America and Madagascar (Whitworth et al., 2016; Olson et al., 2012; and Gregory et al., 2014). This new exciting frontier allows us to study these cryptic species with little effort.

Censuses are difficult, financially expensive and time-consuming and have rarely been carried out in central Amazon relative to the sheer size of this biome and number of primate species. Primates throughout the Brazilian ‘arc of deforestation’, and forests around rapidly expanding urban centers such as Manaus are priority areas for surveying due to the severe and rapidly growing threats. Several attempts have been made to find accurate estimates of population densities and trends throughout the Amazon, but much remains to be done. This is due to a combination of issues that range from funding shortages, remote access to many areas of the Amazon and lack of standardized line transect methods when collecting data.

1.4 Aims and objectives

The overall goal and purpose of this thesis are to estimate primate density and occurrence at Reserve Florestal Adolpho Ducke in the Central Brazilian Amazon. Primates in RFAD have been previously sampled but it is important to monitor their populations due to the great anthropic pressure in the area and thus to verify if their populations are stable or in decline. This study uses two different methods which include distance sampling and the new frontier of arboreal camera trap technology.

Chapter 1 of this study aims to assess the state of primates in Ducke Reserve using the line transect sampling method. There is an increased threat of urbanisation and deforestation in the region; it is imperative that accurate population estimates are produced to monitor primates in this area. This study will also collect ecological data on stratification, group size, heights and distribution throughout the reserve to better understand the way the primates are using the area. Results from this study will, therefore, contribute to future population assessments, monitoring, and conservation programs in this area.

Chapter 2 of this study aims to evaluate how successful camera traps are when assessing primate occurrence in a forest fragment. This research will also assist in creating an inventory of arboreal species at RFAD. Finally, this study aims to develop guidelines on how to solve common issues that occur when using arboreal camera traps. This reserve has extensive data on terrestrial species using camera traps although this is the first studies to apply arboreal camera traps in this area.

Chapter 1: Primate density and use of space in Reserve Adolpho Ducke using distance sampling

2. Introduction

Brazil is one of the most biodiverse countries in the world. It houses many biomes which include the Amazon, Atlantic forest, the Pantanal, Pampas, and the Caatinga. Amazonia covers a total area of 6 million km^2 and spans over nine countries (Da Silva, Rylands, and da Fonseca, 2005). Furthermore, the Amazon encompasses 59% of the Brazilian territory and represents 40% of the world's tropical forest (Almeida et al., 2016). These neotropical rainforests are areas of extreme biodiversity with many areas of endemism (Urbani, 2006) but the Brazilian Amazon is now becoming a hotspot for deforestation with vast tracks of primary forest destroyed every year (Azevedo et al., 2017).

The Amazon is home to the greatest diversity of primates in the world, but several are already threatened with extinction due mainly to deforestation and, to some degree, hunting (Estrada et al. 2018). In spite of such great diversity, Amazonian primates remain the least studied of all primates. In particular, little is known about their abundance and distribution even though such data are essential for conservation action. Thus, in this study, we aim to carry out survey of primates of the Reserve Adolpho Ducke in the city of Manaus. This reserve is one of the most important research sites in the Amazon and is currently under great threat from the rapid urban expansion of the city of Manaus

2.1 Regional Study Area Context

RFAD was established and gained protection status in 1963 and named in honor of the famous botanist Adolpho Ducke (1876-1959) and is one of the most well-known research stations in Amazonia. Significant research has been carried out here on various aspects of tropical forest ecosystems and has provided many guides for species throughout Amazonia. Located North of the city of Manaus, the reserve is an easily accessible and popular reserve in Brazil, and it is essential in maintaining and protecting local biodiversity (Figure 1) (Rodrigues and Vidal, 2011). It was established to be a faraway reserve from the urban hub of Manaus; however, in 2000 the urban expansion of the city reached the southern border of the reserve (Oliveira et al., 2008). The boundaries of this reserve are under severe stress from selective logging, increased hunting pressure and destruction of fences. The proximity to Manaus has allowed the city to develop a small area of the reserve into the tourist attraction MUSA (Museum of the Amazon) a $5km^2$ botanical. It includes a canopy observation tower, forest trails and interactive exhibits which allow tourists to experience the rainforest. It aims to create a sense of protection for the reserve providing it with a way to interact with the city, to bring environmental understanding and education to the urban population by teaching flora and fauna of the Amazon rainforest.

The future of Ducke Reserve is unknown; however, it will eventually become a 'large urban park' instead of a protected scientific reserve (Oliveira et al., 2008), leading to the detrimental future of many species local and endemic to Manaus including the critically endangered Bare-faced tamarin Saguinus bicolor. of the region (Barroso and Mesquita, 2014).

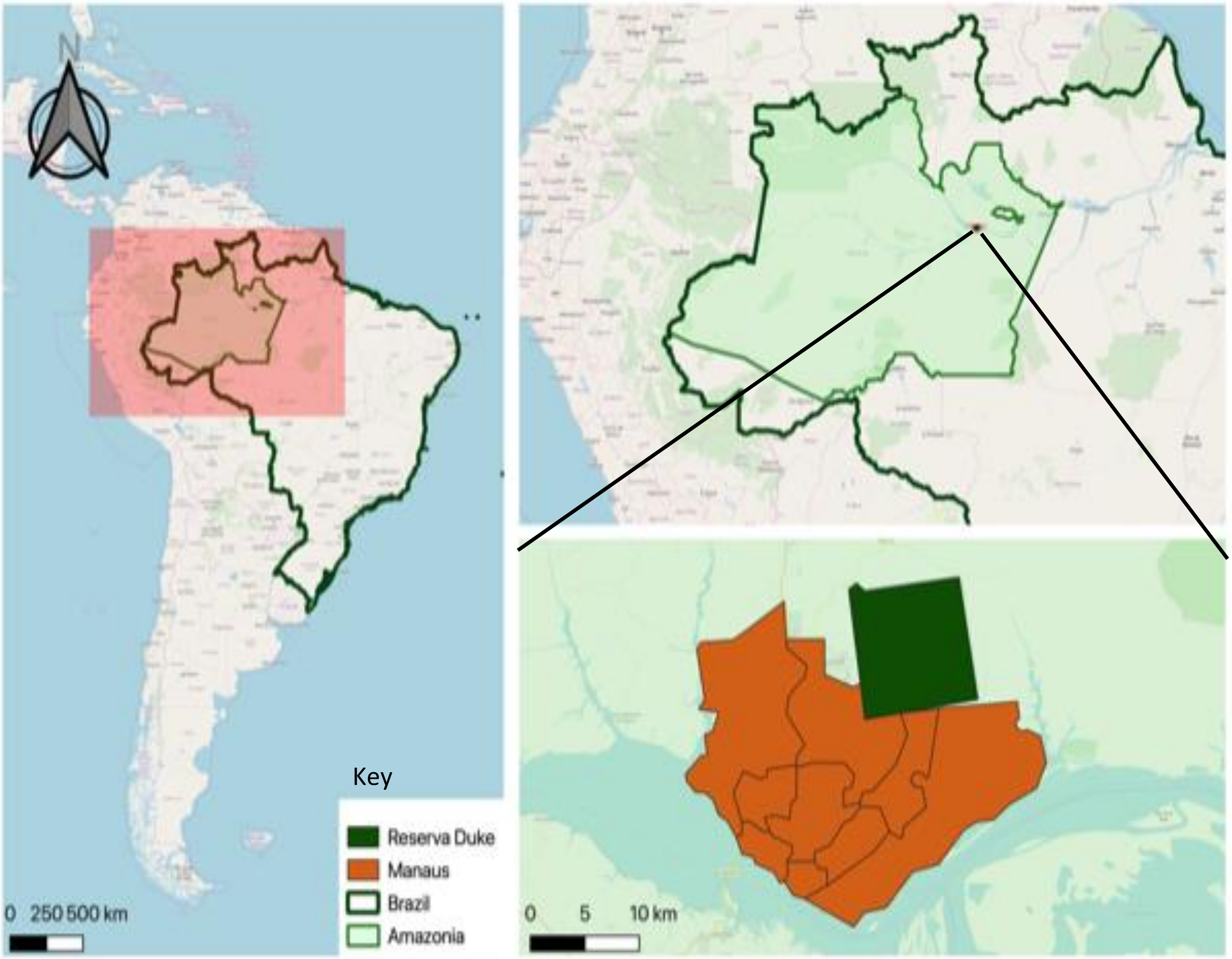


Figure 1. Location of Reserve Ducke in reference Brazil, the state of Amazonas and to the urbanised city of Manaus

2.2 Primates of Ducke Reserve

Since becoming a protected reserve in 1970, only two survey studies on primates at this reserve have taken place (Rosas-Ribeiro et al., 2006, Gordo et al., 2011 and Rodrigues and Vidal, 2011). Primate studies in this area have been focused mainly on ecology and behavior of endangered *S. bicolor* (Gordo, 2012).

Six primate species occur in RFAD which includes: *Sapajus apella*, *Alouatta macconnelli*, *Chiropotes sagulatus*, *Pithecia chrysocephala*, *Ateles paniscus* and the endangered *Saguinus bicolor (*Figure 2*).* Most of these species have large continuous ranges throughout the Amazon, however *S. bicolor* has the smallest range of any neotropical primate with its primary range found throughout forest fragments in the city of Manaus (Gordo et al., 2013; Roch, 2006). This study will focus on five of these species, except *Ateles paniscus* as it was not recorded in this study due to the small area of RFAD it inhabits was not sampled. The current status of these five species is shown in Table 1.

Figure 2. A) *Pithecia chrysocephala. B) Sapajus apella, C) Saguinus bicolor, D) Alouatta macconnelli, E) Chiropotes sagulatus*

Table 1. The current status of five primates found at Reserve Ducke according to the IUCN red list. Source IUCN, 2019.

Family	Species	Common Name	Threat Status	Trend
Pitheciidae	*Pithecia chrysocephala*	Golden-faced Saki	Least Concern	Decreasing
Cebidae	*Sapajus apella*	Large Headed Capuchin	Least Concern	Decreasing
Callitrichidae	*Saguinus bicolor*	Pied Bare-Faced Tamarin	Endangered	Decreasing
Atelidae	*Alouatta macconnelli*	Guianan Red Howler Monkey	Least Concern	Unknown
Pitheciidae	*Chiropotes sagulatus*	Northern Bearded Saki	Least Concern	Stable

2.2.1 *Pithecia chrysocephala*

Pithecia chrysocephala also known as the golden-faced saki is more commonly known throughout local communities as ‘Parauacu’ is found in the Brazilian Central Amazonas, north of the Amazon River and on both sides of the River Negro but northern boundaries for this species are still largely unknown (Figure 3) (Marsh, 2014). Golden-faced sakis prefer mature forests but can inhabit various Amazonian habitats including terra firme, varzea, igapo and palm forests. Regionally the population is stable, but populations near the large city of Manaus, including the fragments around the city, are vulnerable.

Intense studies in this species are rare due to their mysterious, shy nature and their quiet movement through the forest as “ trunk leapers” (Pinto et al., 2013). Most research been carried out on feeding ecology, scent marking, group composition and habitat ecology (Setz 1997,1999 and Marsh, 2014). Soil consumption (geophagy) from termite mounds on tree trunks 2m from the floor has been observed in this species (Setz et al., 1999). It is reported that they are consuming the soil not the termites. Other food sources include fruit, seeds, mature leaves, and insects.

Breeding pair and offspring constitute small family groups of 2-9 individuals making them difficult to detect in the dense forest canopy. Sexual dimorphism is distinguishable from birth with males obtaining a golden rimmed coloured face with a black body, while females have greyish and brown fur and are smaller than the males (Setz and Gaspar, 1997). Unlike many platyrrhine primates, *P. chrysocephala* have no prehensile tail. Males are generally slightly larger than females with tail length is usually measuring 1:1 with body length (average tail length 255-545 and body length 250-980mm) IUCN, 2019.

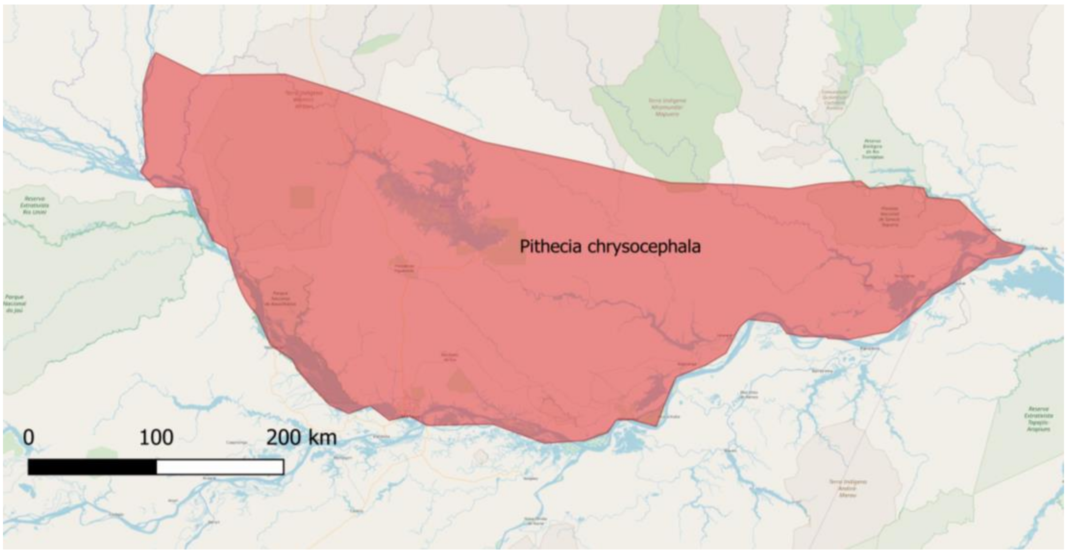


Figure 3. Map of *P. chrysocephala* distribution (Indicated in red) with scale

2.2.2 *Sapajus apella*

Sapajus apella is also known as the Brown capuchin and locally as Macaco Prego. Populations exist throughout Amazonia including Brazil (State of Amazonas, Rondonia, Para and Amapa), Bolivia, French Guiana, Peru, Suriname and Venezuela (Figure 4). Various habitats are used by *S. apella* including palm forests, secondary forests and semi-deciduous forests (IUCN, 2019). Their range is currently not fragmented but has had some local extinctions around human settlements (Encarnacion, 1994).

Capuchins are typically generalist feeders and forage on fruit, insects, seeds, nectar, and small vertebrates (Izawa, 1979, Spironello 1991, 2001) and are the only Neotropical primate to show the ability to use tools. Torralvo et al., 2017 observed capuchins predating upon caiman eggs in the Amazon with 2-4 individuals observed using sticks to dig in the nest to find eggs and are frequently seen using tools to crack nuts open (Struhsaker and Leland,1997).

Males are larger than females with a weight range of 1.35-4.5kg with females slightly smaller at 1.70 – 3.4kg (Jack, 2007). Average group sizes are around 18 individual but can be in groups as small of 5-6 individuals (IUCN, 2019). Males are more dominant in the hierarchy and disperse once they reach sexual maturity.

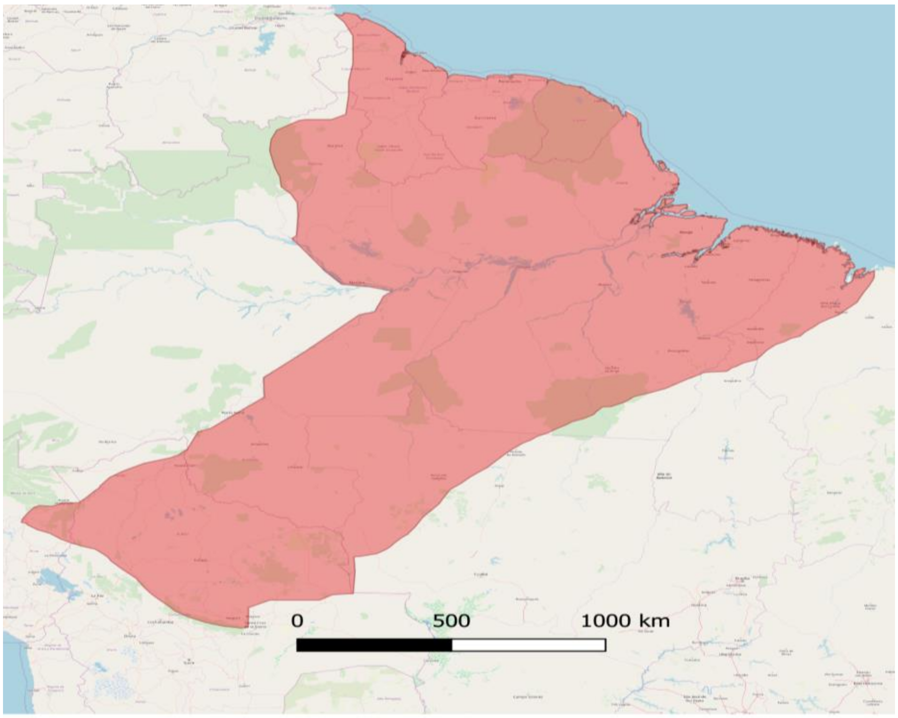


Figure 4. Map of *Sapajus apella* distribution (Indicated in red) with scale

2.2.3 *Saguinus bicolor*

Saguinus bicolor commonly known as the bare-faced tamarin**,** are found throughout fragments in and around Manaus (Figure. 5). It's the only primate to have its entire range within an urban environment and has the smallest range of any neotropical primate (Röhe, 2006). Their range only reaches as far as 35km north of Manaus on the BR174 highway (Subira, 1998), and is becoming restricted to the pressure of *Saguinus midas* who is replacing *S.bicolor* in the north and eastern parts of its territory (Gordo et al., 2013). Other threats which directly affect this species include increased fragmentation of its already limited habitat, the genetic bottleneck for many groups found in fragments in Manaus and the increasing threat of urbanisation (Farias et al., 2015). RFAD is one of the last remaining areas in which genetic bottleneck has not occurred in this species, and the population found here are genetically healthy (Farias et al., 2015). It was recently downgraded from critically endangered to endangered on the IUCN red list. This reclassification was made as they sexually reproduce rapidly; however, their habitat is decreasing and is showing no signs of regeneration.

This species forages on fruits, insects, gum and animals including frogs and small lizards (Elger, 1992, Gordo, 2012). Their group sizes range from 2-15 individuals and twin births commonly observed which is unusual for neotropical primates (Subira, 1998 and Vidal, and Cintra, 2006).

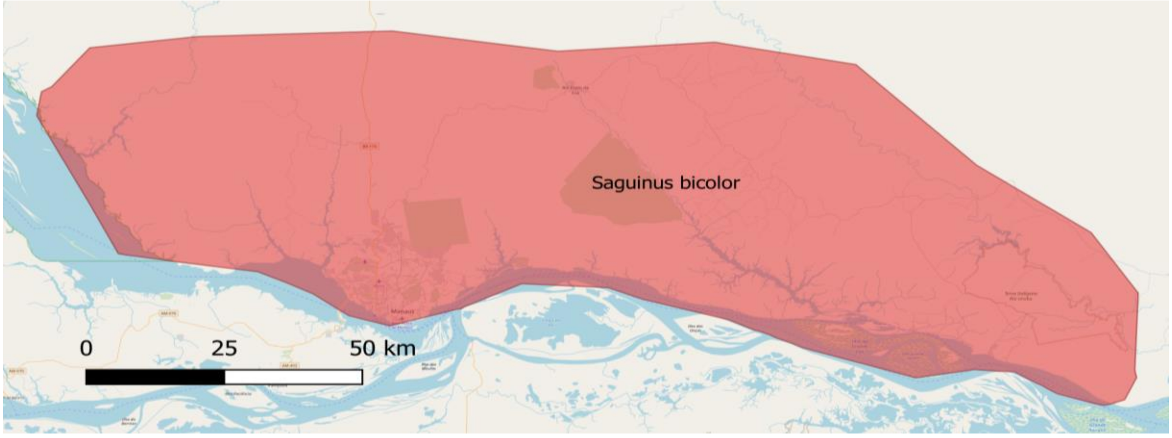


Figure 5. Map of Saguinus bicolor distribution (Indicated in red) with scale

2.2.4 *Alouatta macconnelli*

Alouatta macconnelli also known as the Guyana Red Howler and locally as guarriba can be found throughout most of central and eastern Amazonia including four Brazilian states and five countries; Brazil, Venezuela, French Guyana, Surname and Guyana (Figure 6).

Howlers have a recognisable vocalisation due to a larger hyoid bone in their throat (resonating chamber) which creates a deep grunt like call, and entire groups will roar early morning with calls ranging over 1km (Drubbel and Gautier 1993). Furthermore, calls are usually territorial and space management strategies which cost less energy than physical fights (Ceccarelli et al., 2018).

Group size varies between 5-11 individuals throughout their range but at Reserve Ducke sightings of small groups of 2-4 individuals and solitary individuals have been recorded (Oliveira et al., 2011). Males are larger at 5-7.1kg and female 4-5kg. Multiple feeding studies by Mittermeier and Van roosmalen, 1981, Julliot and Sabatire, 1993 show that howlers primarily feed on leaves with it been reported that 70% of the day is spent relaxing and shredding/fermenting leaves in large caecum’s. Their diet also consists of more diverse options such as fruit, leaves, flowers, and seeds.

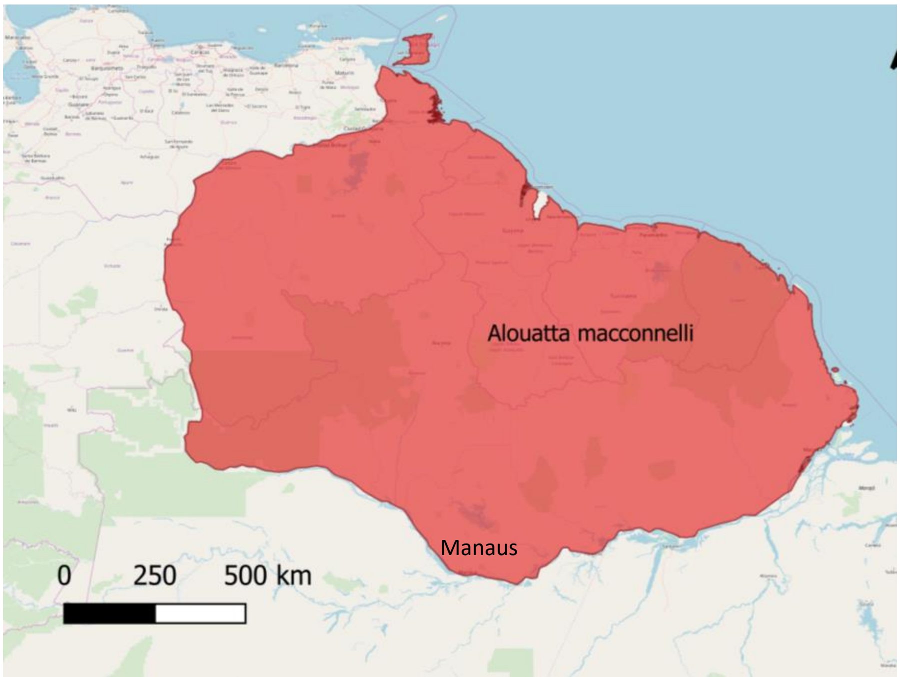


Figure 6. Map of *Alouatta macconnelli* distribution (Indicated in red) with scale

2.2.5 *Chiropotes sagulatus*

Chiropotes sagulatus also known as the northern bearded saki or **cuxiú** (Barnett et al., 2012) 1occurs north of the Amazon river and east of the Rio Negro and Branco up to Guyana, Suriname, and Venezuela (Figure 7) (IUCN, 2019). The genus *Chiropotes* is one of the most understudied genera in the Neotropics (Gregory and Norconk, 2014). This medium-bodied primate occurs in large groups with previous studies at RFAD recording groups of up to 37 individuals (Oliviera et al., 2011) and occurs in groups of 35 individuals at the - Biological Dynamics of Forest Fragments Project (BDFFP) 70km north of Manaus (Marsh and Chapman, 2013). Some studies have reported 60 individuals per group in Guyana (Shaffer, 2012)

Cuxiú live in multi-male multifemale groups, but males have been seen to make affiliative relationships, with reports of all male subgroups (Gregory and Norconk, 2014). Fission-fusion and a decrease in group size occur in the dry season to withstand a period of food shortages. *Chiropotes* have large home ranges of up to 559ha but can survive in fragments as small as 10ha which result in drastically smaller groups of 3-4 individuals (Marsh and Chapman, 2013). Cuxiú are predominantly seed predators and have adapted dental capabilities allowing them to break through seed pods and spend more than 75% of their feeding budget consuming seeds and 12% of their time eating mature fruit (Shaffer, 2013).

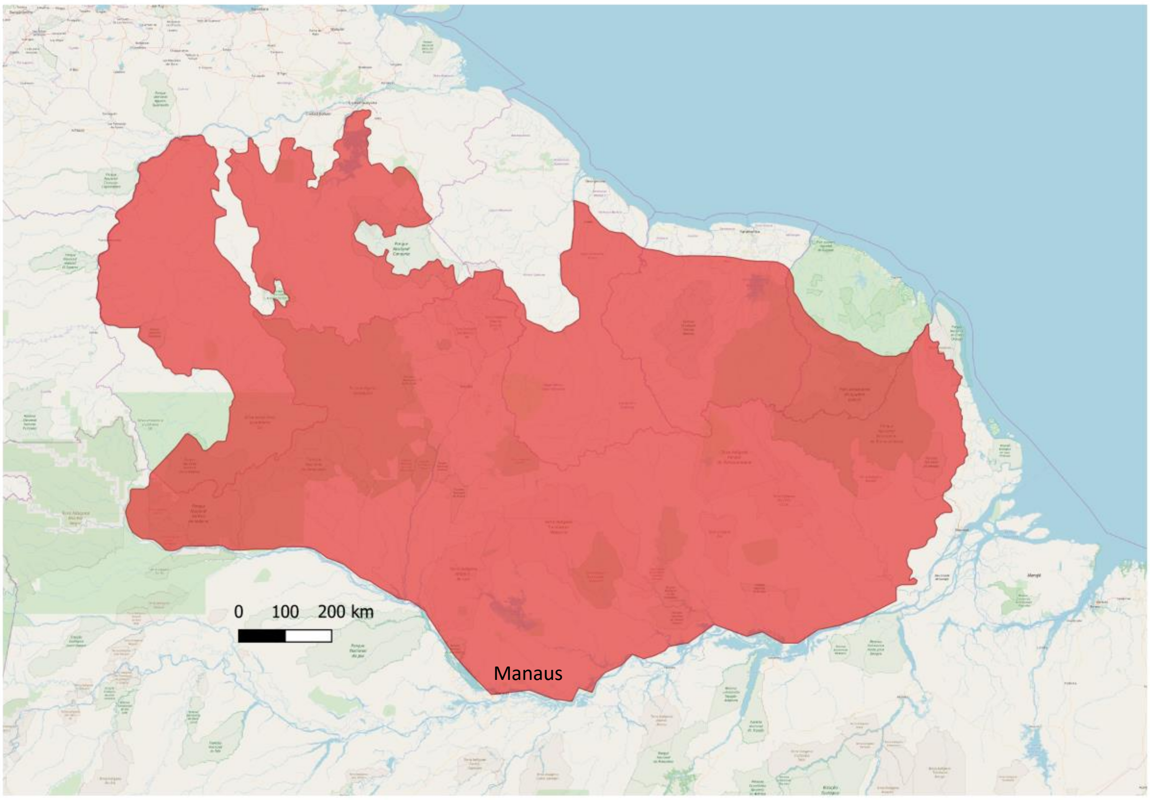


Figure 7. Map of *Chiropotes sagulatus* distribution (Indicated in red) With scape

2.3. Distance Sampling

Several methods can be used to estimate densities of wildlife, such as home range monitoring, complete count, playback, camera traps, and distance sampling (Buckland et al., 2011). Long term monitoring is the most reliable way to gain accurate density and population measures but is expensive and challenging in remote and isolated areas (Hassel-Finnegan et al. 2008). Many studies now use distance sampling. Distance sampling is a selection of methods that use distance measurements from either a point or a line to detect individuals that allows for estimation of abundance and density of a selected species (Thomas et al, 2010). Distance sampling is the primary method used when estimating the abundance and density of mammal populations (Buckland, Laake and Borchers, 2009). It has been successful in gaining accurate density and abundance estimates over a range of studies that expand to multiple species. Detections are not always visual sightings and can also be from vocalisations, nests, tracks and faeces.

2.3.1 Line transects

Line transect sampling is the most common and efficient surveying method used when sampling large diurnal mammals and primate species (Buckland et al. 2009; Spaan et al., 2019) and have been used extensively throughout tropical forests (Wallace, Painter, and Taber, 1998). Line transect sampling for primates has been developed over the last 40 years (Plumptre & Cox, 2005) since the first studies on Malaysian primate densities in 1972 by Southwick and Cadigan, followed by Freese (1975) in Peru.

Line transects consist of random lines situated throughout the habitat following topography elements to ensure there is no habitat bias. One observer starts travelling along the transect line and upon animal detection, the perpendicular distance from the line to the animal and height is recorded. Line transect sampling is the preferred method among field researchers as it allows a and non- invasive way and accurate method for sampling primates (Royle, Dawson and Bates, 2004; Hassel-Finnegan et al., 2008). Line transects have many faults including assumption violations, time-consuming and are expensive.

Sampling wild primate populations can be costly, time-consuming and challenging Gerber, Williams, Bailey, 2014). Furthermore, census techniques throughout primate studies are variable and are still generally non-standardized (Peres, 1999). Neotropical primates are difficult to study in the wild, as they are mostly arboreal making sampling difficult due to the dense vegetation of these habitats. Other obstructions include shy and cryptic species which avoid areas of human activity which is common in the neotropics (Marsh, 2014). These obstructions can lead to the failure of set assumptions (Hassel-Finnegan et al., 2008) but no study is without bias unless full counts and extensive field surveys are completed. The assumptions are: 1) objects of interest on the line are always detected; 2) accurate measurements; 3) objects have not moved before detection; and 4) sightings are independent events.

Many software's can be used to analyze line transect data when attempting to determine density estimates, but there remains doubt over which ones are most reliable. However, DISTANCE 7.0 developed by Thomas et al. (2010) is the most common software used to analyze distance sampling data (Hassel-Finnegan et al., 2008). DISTANCE determines a detection function for the probability of detecting the object of choice at different perpendicular distances and can also account for any missed sightings.

2.4 Chapter Aims and objectives

The aim of this chapter is to use line transect sampling (Buckland et al., 2010) to calculate the density of primates in Reserve Florestal Adolpho Ducke (RFAD), Manaus, Brazil. Geographical coordinates will be taken with a GPS device to map the distribution of primates throughout the reserve. Additional data on stratification and group size will also be collected. The primate density results will be compared with previous studies to evaluate population trends in an area under anthropic pressure.

3 Methods

3.1 Study site

This study was conducted in Ducke Reserve, located north of Manaus, Amazonas, Brazil located along the AM 010 road at the 26km mark. (02 ° 55'-03 ° 01'S, 59 ° 53'-59 ° 59 'W Figure 1). This protected reserve covers 100km^2 of primary terra firme forest which is characterised by a relatively closed canopy with a high abundance of palm trees (Costa et al., 2009). There are two different water drainages in RFAD separated by a ridge that divides these two watersheds. The west side of the ridge drains to the Rio Negro, and the east side drains to the Rio Amazonas.

The regional climate in this area is a hot and humid tropical environment with a mean relative humidity of 80% and annual precipitation of 1,750-2,500mm (Somavilla and De Oliveira, 2017). Temperatures can reach a high of 38.6˚ in the months with higher rainfall (December – May) and can fall as low as 18.2˚ in the dry season (June – November) with an annual average of 26˚ (Costa et al., 2009). The terrain at the reserve varies with most of the reserve relatively flat but altitudes ranging from 80-140m. The soil in the upper areas are predominantly clayey, and the lower areas are dominated by sandy alluvial soils (Oliviera et al., 2008)

3.2 PPBio and the RAPELD system

Current problems with data collection throughout the Amazon have led to incomplete databases with no access to other data collected at sites, lack of environmental data collection, and lack of standardised data. As a possible solution, in 2004 the Brazilian Government launched the Program for Biodiversity Research (PPBio is the acronym for the Portuguese name – 'Programa de Pesquisa em Biodiversidade'). This program was put in place to increase knowledge on Brazilian biodiversity by coordinating and standardising data collection, create monitoring programs and provide conservation and monitoring training.

PPBio aims to standardise data collection by following the RAPELD system (RAP stands for Rapid Assessments Program, and PELD is the acronym for long term ecological research in Portuguese, 'Pesquisas Ecologicas de Longa Duracao). The RAPELD system is a permanent 25km^2 grid plot (Figure 8). Every 1km, there are smaller plots of 250x40m which follows the terrain contour lines and topography of the field site (Oliviera et al., 2008). This system is used throughout various Brazilian reserves and is expanding to other countries such as Africa and Australia. Ducke Reserve was the first reserve to have the RAPELD system and is run by National Institute of Amazonian Research (INPA). All the data collected in the RAPLED system is deposited on a data portal which is available for two years after data collection.

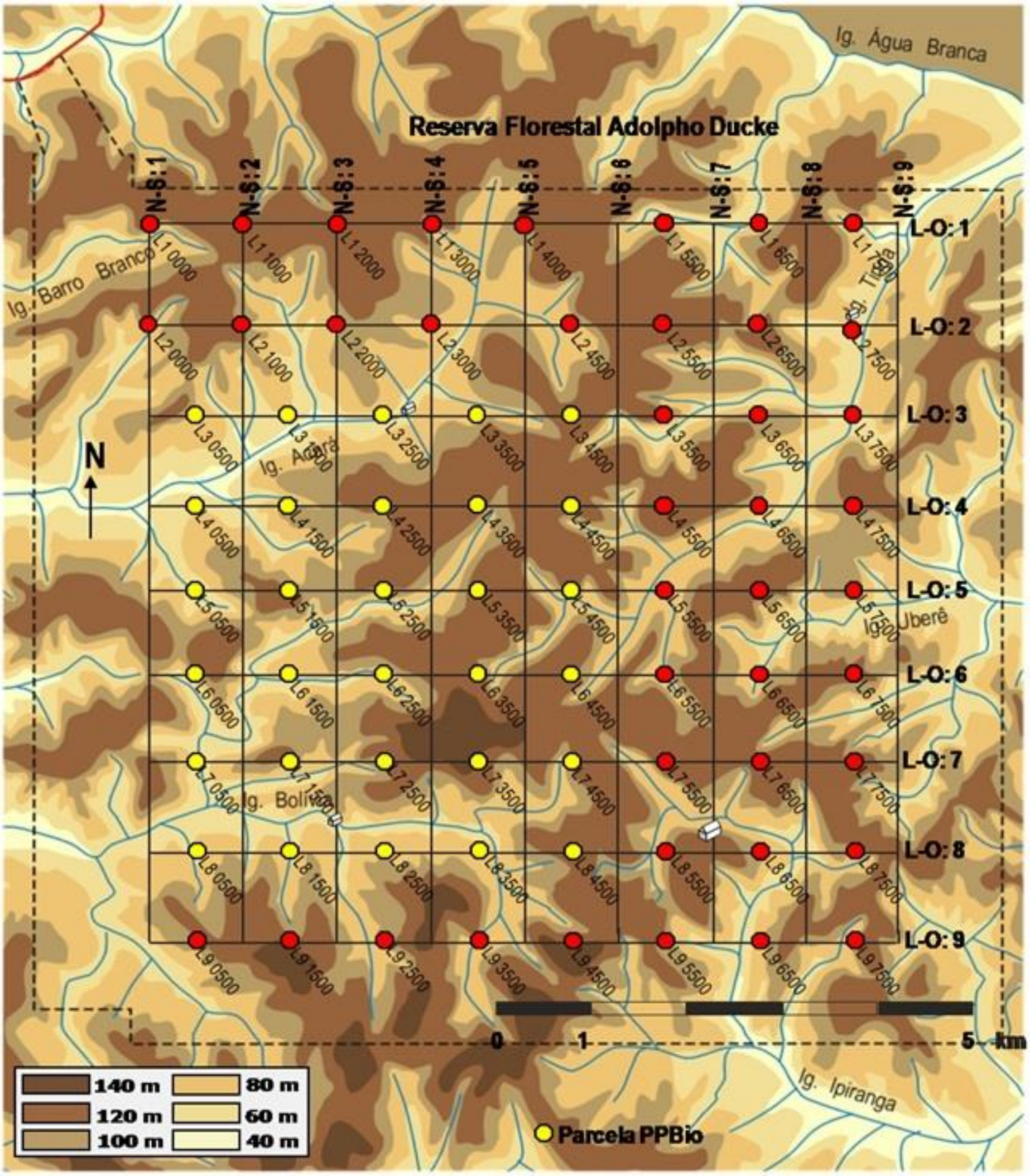


Figure 8. Image of the trail system at Reserve Floresta Adolpho Ducke. Yellow markers identify the smaller 25km^2 RAPLED plot with the red markers representing the larger grid system at the reserve Source: INPA

3.3 Sampling design

Diurnal line transect surveys were conducted to estimate density estimates of primates at Ducke Reserve. This study followed distance sampling assumptions, guidelines and recommendations set out by Buckland et al., 2010.

Due to many previous and current intensive studies, trail systems were already established and cleared before this study commenced. Data was collected in the rainy season over 50 days between February-May 2018 using nine transects all 5km in length (Figure 8). Transects ran parallel to each other and were separated by 1km with all transects marked every 100m with location and measurement tags. Transect lines were repeated multiple times (Table 2) and by following transect protocols, no transect was repeated on the same or following day to ensure transects were rested between sampling. Transect 1-6 were repeated more often as more days were spent at the main camp which allows easier access to this part of the reserve. As fewer days were spent at camp “Bolivia” resulting in transects 7-9 been repeated and sampled less.

Table 2 . Total effort on transects, repetitions, transect length

Transect	**Length (km)**	**Repetitions**	**Total effort (km)**
1	5	8	43
2	5	9	45
3	5	7	35
4	5	6	30
5	5	6	30
6	5	6	30
7	5	2	10
8	5	2	10
9	5	3	15
Total	**45**	**49**	**248**

3.4 Sampling Protocol

One observer and a field assistant walked one transect in the morning (6-11am) and one transect in the afternoon (12:45-4:30 pm). Midday hours were not walked to avoid hours when primates are less active. Transects were walked at an approximate speed of 1km/hour.

To maximise the chance of detecting primates, the observer stopped for 60 seconds every 50m to listen for vocalisations, fruit falling, and movement. Due to poor visibility, and noise, transects were not conducted when raining. If it started to rain when the transect had already been started, observers would stop and wait until the rain stopped. Various camps at the reserve were utilised to make it easier to begin transects at the correct times which includes the Main camp in the North- West, Tinga in the Northeast and camp Bolivia situated in the Southwest corner of the reserve

Upon detection of a primate, the following data were collected: 1) time of detection; 2) primate species; 3) number of individuals; 4) perpendicular distance to transect; 5) height of the animals, and 6) location given in geographical coordinates by a GPS handheld device (Garmin Map 63). When possible, sex and age were also recorded. Height and perpendicular distance and sighting distance were recorded using a Nikon forestry pro range finder. Perpendicular measurements are recorded from the transect to the centre of the group cluster. Stopping to collect data was limited to 10 minutes.

Primates at this reserve are not habituated making it challenging to collect the age and sex of each individual in the time available to collect all measurements. Groups were only considered to be independent or separate when found to be more than 100m apart. If a GPS device was unavailable on the day, the location on transect was recorded by using the available trail markers or poles which are every 100m. In such cases, the distance from the point of observation to the nearest pole was taken.

A preliminary and exploratory study was conducted before the main study. This took place for seven days between January 27th and February 3rd, 2018. This preliminary study aimed to practice surveying primates using the line transect method to perfect the technique and learn the vocalisations and movements of the primates at RFAD. In this period trails 1 – 5 were walked which run west to east (Figure 8). Transects 1/2/5 repeated twice with transects three and four were repeated three times.

3.5 Analysis

All line transect data were analysed using the software DISTANCE 7.0 release 1 (Thomas et al., 2010). DISTANCE software was used to create individual and group density estimates and calculate the average group size. Due to the lack of sightings, the two saki species *C. sagulatus* and *P. chrysocephala* were grouped to create a more substantial data set amenable to be run in DISTANCE. Density estimates and average group sizes were calculated for each species. All data collected during the study was saved in text files to be readable by Distance. Data required to be in a separate folder included the size of the reserve, transect number, effort on each transect, perpendicular distance and size of the cluster. See supplementary materials for details on how distance was used in this study.

3.5.1 Truncations

Truncation is performed in situations when collected data do not fit well to any models and detection functions. Left truncation is required in cases where the first assumption of the distance sampling method is not met, i.e., when animals are detected less than 100% of the time when above or on the trail. This happens in cases when the view of the line above is obstructed and inadequate or if animals are aware of the trails due to potential threats (e.g., hunting). Right truncations are done when there is a sighting far away from the line. No right truncations were used in this study. Truncation removes some data and detections before final analysis resulting in a smaller sample size. In this study, truncations were made with two species - *A. macconnelli* and the grouped data of *Pithecia* and *Chiropotes.* This was decided to fit the model and histogram best.

3.5.2 Models and key functions

All data was run through DISTANCE software, and there was no requirement to calculate density estimates manually. Density [1] is calculated using this equation: D = density estimate, n = number of animals and a = sample area.

$$\widehat{D} = \frac{n}{a} \qquad [1]$$

Frequencies of observations decrease as a function of the perpendicular distance, which makes for missed detections. Distance makes up for any possible missing detections which can be worked out using [2] where p = estimate of the proportion of detected animals, g(0) = all animals on the transect detected, w = perpendicular distance from transect, g(x) = probability of detection, u = perpendicular distance at which the number of undetected animals at distances less than u is equal to the number of animals detected at a distance greater than u.

$$\hat{p} = \frac{\int_0^w \hat{g}(x)dx}{g(0)\times w} = \frac{\widehat{\mu}}{g(0)\times w} \qquad [2]$$

Several suitable combinations of models can be chosen which includes: 1) uniform with cosine adjustments, 2) half normal with cosine, 3) half normal with Hermite Polynomial and 4) hazard rate with Simple Polynomial. Different models are chosen for each species dependent on the Akaike information criterion AIC and the P value. Also, a visual assessment of model fit is made by examining the histograms for the best fit. The lowest AIC is selected once each model has been run through distance and is compared. The AIC provides a relative measure of fit. It finds the best fit with the fewest parameters. The P. value for each species was also considered for each species.

4 Results

The model chosen for each species are as follow:

*Pithecia chrysocephala/ Chiropotes sagulatu*s – Half normal with no cosine adjustment

Saguinus bicolor – Half normal with no adjustment

Sapajus macrocephalus - Uniform simple with one simple polyandry adjustment

Alouatta macconnelli – Uniform with one cosine adjustment

4.1 Primate detections

In a total sampling effort of 248km over nine transects, I recorded five primate species in 103 detections (sightings). Overall brown capuchins *(Sapajus apella)*, golden-faced saki's *(P. chrysocephala*) and guianan red howler *(A. macconnelli)* had the largest number of detections, while bare-faced tamarins (*S. bicolor)* and northern bearded saki's (*C. sagulatus*) were seen the least during the study period (Table 3). *P.chrysocephala* and *A. macconnelli* were left-truncated when running through distance. This resulted in the loss of detections including losing 2 *P. chrysocephala* and 4 *A. macconnelli* (Table 3).

Table 3. Overall detections and number of detections once truncation occurred. Also, average and range of groups sizes and height are displayed here.

Species	**Detections**		**Group Size**		**Height (m)**	
	Overall Detections	Detections after truncation	Mean	Range	Mean	Range
Sapajus apella	44	44	6.98	2-12	14.1	6-23
Pithecia chrysocephala	18	16	2.93	1-6	12.5	6-19.8
Saguinus bicolor	16	16	4.6	1-9	14.2	5.6-29.2
Alouatta macconnelli	19	15	3	1-5	17.5	8.8-27
Chiropotes sagulatus	11	11	8.81	1-20	14.5	5.6-28.6

Detection for each species varied each month of the study. *S. apella* were the most sighted species in three of the four months with a spike of detections in April. *S.bicolor* were present in February, but sightings declined in the last three months of the study. Sightings of *P. chrysocephala* were consistent throughout the study and did not ever exceed five detections every month, and finally, *C. sagulatus* had low detections throughout the study never reaching more than six sightings (Figure 9).

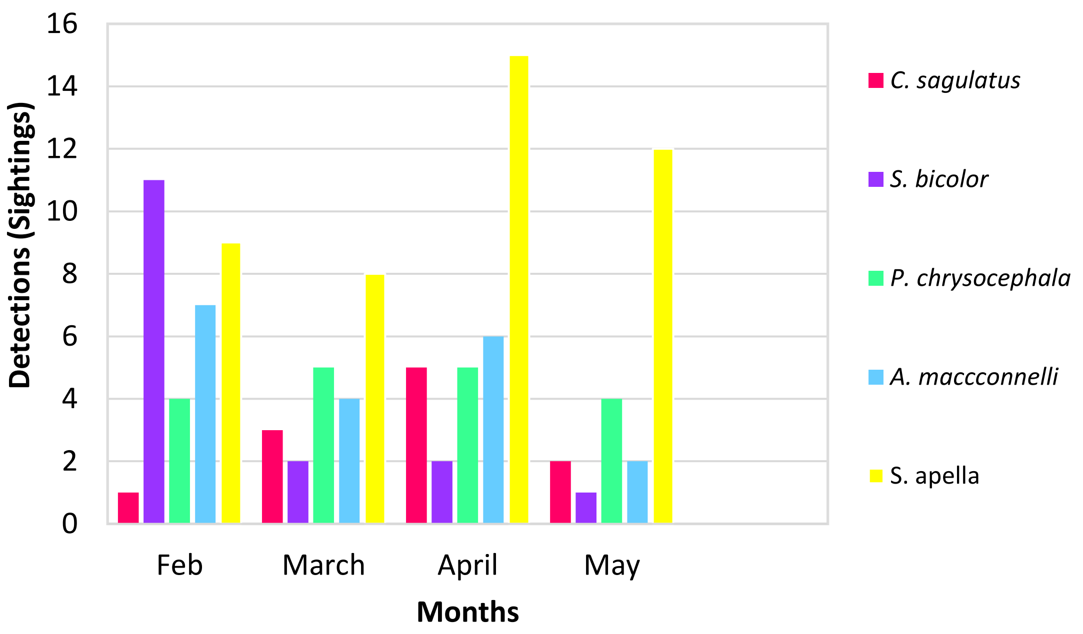


Figure 9. Detections of each species throughout the study period per month

4.2 Primate GPS data

QGIS was used to produce a map of primate sightings throughout the study area where each point is a primate detection (Figure 10). Fewer sightings occurred on transects 7-9 as the area was less sampled. The majority of detections occurred on Transect 1 and 3.

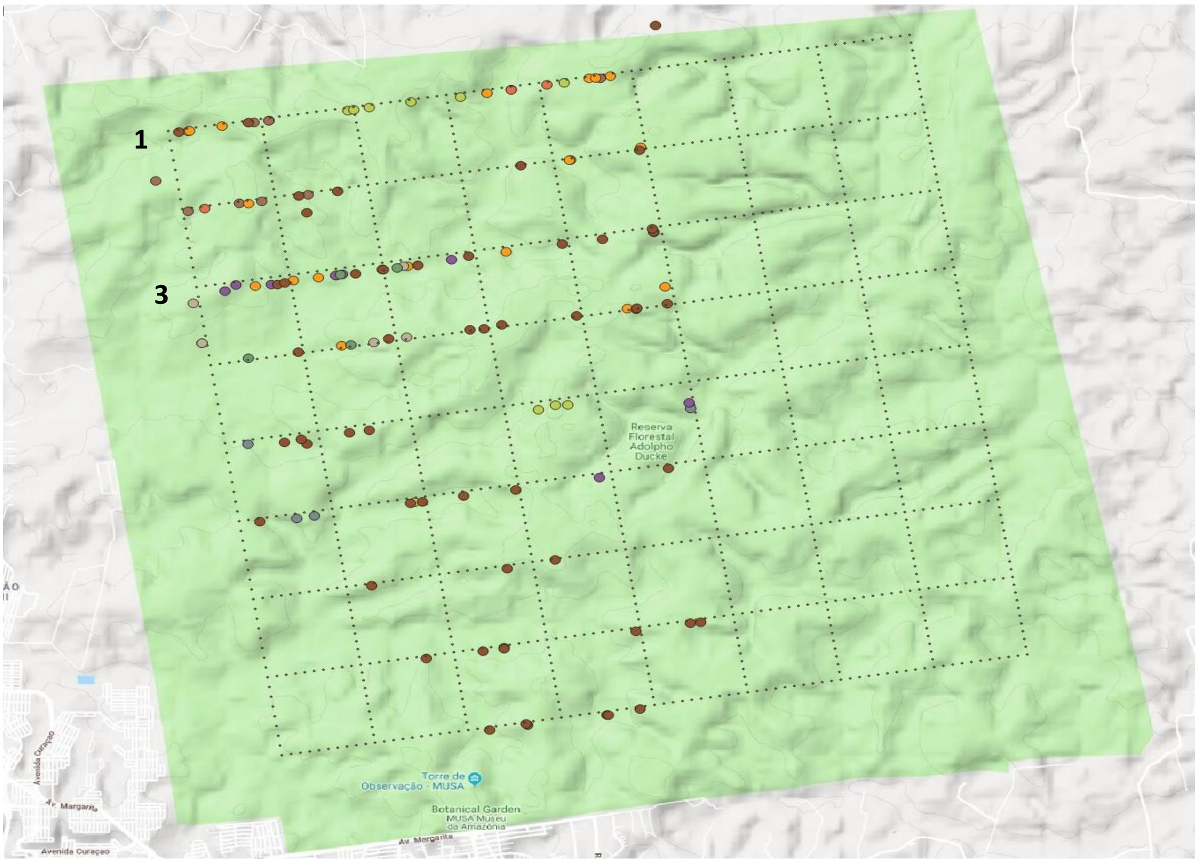


Figure 10. Map with GPS points of all detections in the study period. Transect 1 and 3 highlighted

4.3 Primate group size and heights

A. macconnelli occurred at the highest in the canopy at a mean average of 17.5m followed by *C. sagulatus* at 14.5m with *S. bicolor* at 14.2m and *S. apella* at 14.1m. *P.chrysocephala* ranged much lower in the stratum at 12.5m (Table 3). Although *P. chrysocephala* was on average found much lower in the striatum, *C. sagulatus* and *S. bicolor* occurred at the lowest height overall with both at 5.6 m. The lowest height overall for *P. chrysocephala* and *S. apella* was at 6m. *A. macconnelli* had the highest height range occurring lowest in the stratum at 8.8m but also occurred high in the canopy at 27m. *S. bicolor* also occurred high in the canopy occurring highest at 29.2m followed by *C. sagulatus* at 28.6m. Lower heights belonged to *S. apella* at 23m, and *P. chrysocephala* is occurring lowest in the stratum at 19.8m (table 3).

4.4 Primate Densities

Only *S. apella* reached the minimum number (40) of detections recommended when estimating densities with line transects and distance software (Buckland et al., 2010). The species with the highest individual density/km^2 was *S. apella* with 19.33 individuals/km^2. The species with the lowest individual density was *P. chrysocephala* with 3.76 individuals/km^2. The species with the highest group density was *A. macconnelli* with 3.16 groups/km^2 and the species with the lowest group density was *C. sagulatus* with 0.88 groups/km^2. Distance showed that different models and adjustments had to be used for each species with the lowest AIC values always determining the chosen models for all primate species. For all analyses information see Table 4.

Table 4. Results taken from distance 7.0 software including individual and group densities, cluster size, AIC used, truncations and coefficient variants (CI and CV). ESW = Effective strip width, AIC – Alkine information criterion.

Species	Number of sightings	Maximum sighting distance (m)	Number of distance intervals	Truncation distance (m)	Model/ adjustment term	AIC	ECW (CV)	GOF$^{(df;p)}$	Density (ind.km^{-2}) (CI; CV)	Density Group.km^{-2}(CI;CV)	Cluster size (CI; CV)
Alouatta macconnelli	5	40.8	4	15	U + 1 cos	38.60	9.1 (26.61)	23 (2; 0.53)	9.4 (4.60-19.50; 36.18%)	3.16 (1.57-6.35; 34.68%)	3.0 (2.4-3.7; 10.29%)
Sapajus apella	4	59	10	-	U + 1 sim	183.06	30.57 (9.35)	5.19 (7; 0.63)	19.33 (12.29-30.40; 21.89%)	2.76 (1.81-4.22; 19.83%)	6.98 (5.79-8.42; 9.28%)
Chiropotes sagulatus	1	32	4	5	H-N	76.52	23.78 (25.78)	0.93 (2;0.62)	5.54 (1.89-16.24; 55.93%)	0.88 (0.40-1.93; 38.82%)	8.81 (5.26-14.77; 23.48%)
Pithecia chrysocephala	6	32.8	4	5	H-N	76.52	23.78 (25.78)	0.93 (2;0.62)	3.79 (1.46-9.87; 47.62)	1.29 (0.50-3.32; 46.75%)	2.93 (2.42-3.56; 9.04%)
Saguinus bicolor	6	35	4	-	H-N	45.92	28.78 (46.03)	0.07 (1; 0.79)	4.3 (1.69-9.41; 39.59%)	1.05 (0.50-2.22; 36.98%)	4.06 (3.01-5.48; 14.12%)

4.5 Distance data

The histograms produced by distance in Figure 11 and figure 12 show varied differences in distribution. The default graph (Figure 11) shows that *S. apella* needed no truncations and data fit the function well and showed no sign of error in data collection. *P.chrysocephala* and *C. sagulatus* show that more data was collected further away from the transect line with spikes in detections at 16m with lower detections between 0-10m. The most drastic truncation occurred with *A. macconnelli* with truncation on 15m. This species had a significant spike in sightings at 20m. Figure 12 shows the histograms after truncation and adjustments. Here the data fits the detection functions much better. Changes were made to the number of intervals for each species with *S. bicolor* having four intervals, *S. apella* having 8, *P. chrysocephala* and *C. sagulatus* having 4 and *A. macconnelli* 4.

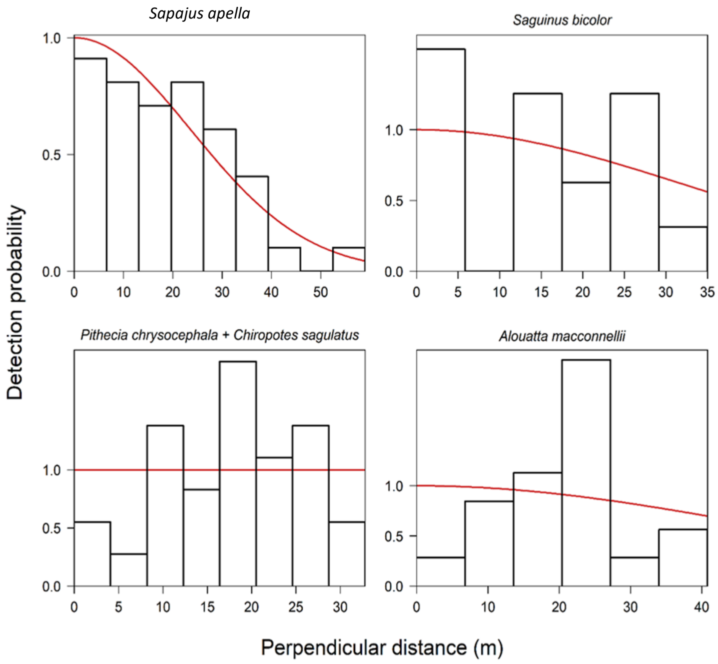


Figure 11. Default graph of all species after been run through DISTANCE as half normal cosine with no adjustments or truncations. This shows how the data is sitting and the decisions needed to be made for a better histogram curve.

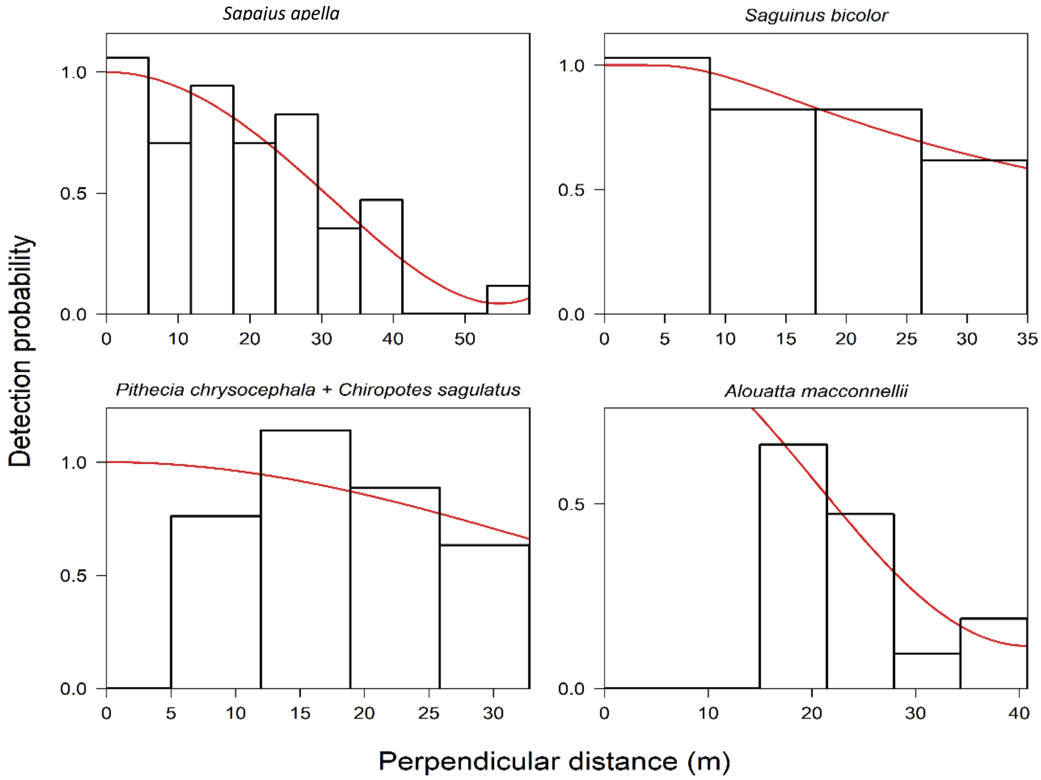


Figure 12 A) *S.apella* detection probability with a uniform function and a simple polynomial adjustment, B) *S. bicolor* detection probability with a half normal function with no adjustment, C) *A. macconnelli* detection probability with a uniform function and a cosine adjustment and a 15m left truncation. D) *P. chrysocephala* and *C. sagulatus* detection probability with a half normal function with no adjustment and 5m left truncation.

4.6 Interspecific associations

Data collected on interspecific associations were collected opportunistically during the line transect sampling. Recording these interactions were not an initial aim of this study but were frequently seen during the study period. A total of four interspecific associations were recorded in this study where three interactions occurred early morning between 6:20 am – 8:08 am and one happening early afternoon at 1:30 pm. *S. apella* was present in all associations. Two of these interactions occurred between *S. bicolor* and *S. apella*. In both instances, both species were foraging but in different trees. *S. apella* was viewed on one occasion with *A. macconnelli* resting in some trees. Only one individual of *A. macconnelli* was spotted with the three of *S. apella*, and it is unclear if there were more individuals spread out beyond the view of the observer. A large group of 10 individuals of *S.* apella was also observed foraging with five individuals of *C. sagulatus.* As primates at RFAD are not habituated, once they were detected, they fled leaving the observer unable to observe these interactions further. Interactions are as follows: (1) 22/2/18 – *S. apella* (3 individuals) and *A. macconnelli* (1 individual) on Transect 2 at 7:15 am; (2) 28/2/18 – *S. bicolor* (2 individuals) and *S. apella* (2 individuals) on Transect 1 and 06:20 am; (3) 28/2/18 – *S. bicolor* (1) and *S. apella (*6) on transect 2 at 1:30 pm ; and (4) 1/3/18 – *S. apella* (10) and *C. sagulatus* (5) on transect 3 at 08:06 am.

5. Discussion

This is the first study after 12-year time to estimate the density and group sizes of all primate species at Reserve Adolpho Ducke. Only two previous primate density studies have been undertaken at this reserve (table 5) which resulted in varying density estimates, although another study is underway conducted by N.M. Kinap. Studies on *S.bicolor* have been prioritized as it is an endangered species whose range predominantly exists in Manaus and part of municipalities of Rio Preto da Eva and Itacoatiara. All other primates have been studied less as they are found in other areas of the Amazon and have large unfragmented ranges.

The number of primate species recorded (5 species) in this study is the same for other studies at RFAD (Vidal and Rodrigues, 2011 and TEAM). RFAD has a considerable number of species for its size and compared to other areas around Manaus including the BDFFP project found 70km north of Manaus with the exception for *S. bicolor* whose range does not go that far north (Röhe, 2006; Boyle et al., 2013).

Table 5: Density of primate groups/km^2 and individuals/km^2 in this study and two other studies on primates at Ducke Reserve.

Study	**Year**	**Density Groups*km^2/Individual*km^2**					
		Alouatta macconnelli	*Sapajus apella*	*Chiropote sagulatus*	*Pithecia Chrysocephala*	*Saguinus bicolor*	Total effort Km
Current study	2018	3.16/9.4	2.46/19.3	0.88/5.5	1.29/1.3	1.05/4.3	248
Rodrigues and Vidal	2011	0.66	0.67	0.30	0.64	1	720
TEAM	2006	2.5/11.9	0.31/4.4	1.19/9.0	1.97/3.8	1.14/6.6	576

A small period was spent at the camp Ipiranga which is located in the South East corner of the reserve. However, surveys could not be completed here as all trails were unkept and closed making it impossible to follow line transect assumptions. *A. paniscus* was not seen, but vocalisations of this species were heard in this area indicating their presence. This finding corroborates the previous studies which the species was recorded (Rosas-Ribeiro et al. 2006, Gordo et al. 2011, Rodrigues and Vidal, 2011). Also, with the increased hunting pressure large-bodied primate species would be the first to be affected and could be an important indicator of how human presence is affecting primate abundance at RFAD (Gordo et al. 2011).

5.1 Primate densities

Monitoring primate densities at RFAD is important because of the anthropogenic effects from the pressures on the edges of the reserve. Through continuous monitoring it will be possible for us to assess how this is effecting primates at RFAD but currently it is impossible for us to discuss variations as our sample effort is too low. However it is clear by looking at previous studies that primate densities found in this study are most similar to those found in the TEAM survey but a lot higher than those found by the 2003 study by Vidal and Rodrigues (2011). This study had a lower effort size compared to Vidal and Rodrigues and TEAM (Table 5). Effort size is important when estimating density and is advised that at least 100km per transect is recorded to produce reliable density estimates. Accumulating this amount of data would lead to more reliable density estimates, however, this amount of sampling is impossible to complete for this study due to time constraints. However, despite TEAM having a greater sampling effort (3 years, including rain and dry seasons), the results are almost equivalent, excluding *Sapajus apella* (19.3 ind.km^2 versus 4.4 ind.km^2 of TEAM).

5.1.1 A. macconnelli and *S. apella*

A.macconnelli had the largest density of groups at RFAD which was also much larger than the previous studies. This was also the same for *S. apella* who had the largest individual density. The larger densities could be due to the population recovering in the 12 years since the previous study. Fedigan and Jack (2000) found that howler monkey populations recover faster than capuchins but both recover differently. Howler monkeys were found to create new and smaller groups whereas capuchins made their groups larger mirroring what this study found. *A. macconnelli* have the highest group density at this reserve but have low individual density and small group sizes. This means that although there are many small groups of *A.macconnelli* at RFAD, *S. apella* are the most abundant species as they had larger group sizes with more individuals.

There are many reasons why *S. apella* is thriving at RFAD including; 1) Diet; 2) travels in large groups and 3) ecology. However, this species is not known to survive well in small fragments and has been hunted into local extinction in areas in the Amazon. As RFAD is getting cut off from continuous forest it could threaten *S. apella* in this locality. It is also a “confident” species and does not always flee at human presence making it an easy target. Furthermore, adult male capuchins have been seen distracting humans so other members can escape.

The density estimates could be subject to change and may increase if more sampling is completed. *A. macconnelli* were often seen far away from the transect line, primarily due to issues detecting the species due to its cryptic and cautious behaviour. As distance software makes up for missed sightings the truncations could have overestimated the number of missed groups which could have led to higher estimates.

5.1.2 Saguinus bicolor

The group density for *S. bicolor* is similar in all three studies (Table 5) that have been carried out in RFAD (Gordo et al. 2011; Rodrigues and Vidal, 2011; Gordo 2012), with little difference between the estimates. Only small differences were noted in their individual density with this study estimated 4.3ind/km2 whereas TEAM, 2006 estimated 6.6ind/km^2. The density at RFAD is stable and one of the only areas to hold substantial numbers of *S. bicolor*. Oher areas and fragments that this species is found are small and have no protection. Preserving RFAD is in the best interest of this species for its future viability.

5.1.3 *Pithecia chrysocephala*

Pithecia chrysocephala has no previous density studies throughout its range other than RFAD. This species up until recently was considered a subspecies of the White-faced Saki (*Pithecia pithecia)* but was raised to full species level in 2014 (Marsh, 2014). There is still dispute about if this is a different species resulting in insufficient data for this taxon. One of the only differences between *P. chrysocephala* and *P. pithecia* is the distribution and colour variation of the face of males. Density estimates are comparable to that of the other two previous studies at the reserve (Rodrigues and Vidal, 2011).

5.1.4 *Chiropotes sagulatus*

This species does not appear on IUCN as *C. sagulatus* and is under *Chiropotes chiropotes*. The density estimates in this study are higher than that from Vidal and Rodrigues, 2011 but lower than that from TEAM, 2006. It was the lowest density for any of the primates at the reserve. *C. sagulatus* are known to sleep and forage in smaller groups and then band together in larger groups. This was seen throughout the study with groups ranging from 1 - 25 individuals.

5.2 Competition between *Saguinus bicolor* and *Saguinus midas*

RFAD is one of the largest areas of forest that contains genetically healthy groups of S. bicolor (Farias, 2015). As discussed in many studies, S. bicolor cannot coexist with S. midas (Rohe, 2006; Gordo, 2012; Gordo et al., 2013) due to S. midas been far more aggressive and competitive, leading to competitive exclusion. It is common knowledge that S midas is slowly expanding its range throughout Central Amazonas and is closing in on the range of S. bicolor. Worryingly, there is no hard-physical border between the species throughout the northern edge, and S. bicolor has gradually become surrounded and pressed into an urbanised metropolis.

A sighting of *S. midas* was made during this study at RFAD. No pictures were taken of this event but both myself and a field assistant observed this sighting. Moving forward to reconfirm this sighting ,monitoring should be conducted to assess the extent of *S. midas* in the reserve using camera traps, e dna and monitoring of the reserve.

5.3 Interspecific interactions

Interspecific interactions are a common occurrence throughout primate communities in the Neotropics. This study found that *S. apella* was the main species seen in these interactions. Many interactions have been witnessed in the genus *Sapajus* and *Cebus* throughout current literature. *Cebus* have been seen interacting with *Alouatta* and *Atele*s in grooming and playful behaviour (Rose et al., 2003). Interactions have not only occurred with other primate species but with entirely different species such as Coatis (Resende et al., 2004). Interactions observed were never aggressive, and individuals were seen playing and grooming coatis, but other studies have reported capuchins raiding coati nests and taking their young (Rose et al., 2002). *Sapajus apella* have been known to travel and forage with *Saimiri sciureus* in the Amazon. These interactions are thought to be related to predator protection, foraging efficiency and to dominate food sources (Haugaasen and Peres, 2009). Further research is needed to find out why capuchins frequently interact with other species as literature on interspecific interactions in the Neotropics predominately feature capuchins.

5.4 Group sizes

Primate group sizes are widely influenced by resource and habitat quality/availability. When collecting group size data in census the observer is rarely able to correctly count all individuals due to individuals out of sight of the observer and time limitations when collecting data. However, data from this study suggests that group sizes have remained relatively stable since the last study 12 years ago (Rodrigues and Vidal, 2011). *A. macconnelli* group sizes were similar to observations made at this reserve previously (Oliviera et al., 2008). *C. sagulatus* occurred in smaller groups at RFAD (average of 8.81 and maximum 20 individuals) than they traditionally occur in. 70km north of RFAD at the BDFF project groups of up to 36 individuals have been observed. *Pithecia chrysocephala* typical live in small group sizes with an average of 2-8 individuals which usually consist of family groups of one adult male and female with several young (IUCN, 2019). Group sizes in this study correspond to current literature and also with one previous study at RFAD (Rodrigues and Vidal, 2011). *S. apella* tend to occur in large groups with a mean of 18 members (IUCN, 2019). This study had a much lower average of 6.98 individuals.

5.5 Detections per month

Many factors determine primate occurrence and abundance including food availability, predation and habitat suitability (Rossano and Pontes, 1999). Fruit availability is believed to be the most important factors affecting primate abundance and occurrence in the Amazon rainforest (Hanya et al., 2010). Fruit production in the Amazon is seasonal with the frutification peak occurring in the rainy season around January to March. However, as data was only collected in the rainy season there is no way of comparing it with the dry season (period of scarcity of resources). From the knowledge gained from a local field assistant led me to believe that fruit availability occurred more prominently in certain areas of the reserve (Transects 1-4). This is where the majority of sightings were made during the sampling. However, RFAD does not have any data demonstrating fruit availability within the reserve, but variability is normal within a landscape. Further research could be done at RFAD to understand which areas of the reserve has more intense fruitification and how this is effecting primate occurrence.

5.6 Hunting/ Urbanisation

Data on hunting in RFAD is still deficient, but primate populations close to human-disturbed areas are known to become locally threatened or in the worst case, wiped out completely (Araldi et al., 2014). Therefore, it would have been logical to think that the primate densities at this reserve would have fallen due to the rapid expansion of Manaus and the increased human activity (hunting) throughout the reserve over the last 12 years. This preliminary study, however, indicates that primate density in this reserve appears to have remained stable with *A. macconnelli* and *S. apella* having larger densities. This has led us to believe that populations may have recovered since the previous studies.

To better understand the way urban environments are effecting primates at RFAD, we need to frequently asses primate densities to track trends. In addition, data collection should be systematic and data should be collected so it can be combined and compared. As previously stated that RFAD will become an urban park, this potentially could be a good way to study how primates are effected by urbanization in the neotropics.

Such action is urgent because during this study hunters were frequently seen throughout the forest. Hunters were seen collecting animal products, cooking caiman and fish and removing large amounts of fruit. In addition, bullet casings, girau and damaged trees are more frequently seen closer to the city rather than in the interior of the reserve (figure 13).

Figure 13. Images taken during the study period including bullet shots in trees, wooden ladders made to extract fruit from a fruiting tree, remains of a cooked caiman and a girau

5.7 Implications and recommendations for conservation

Ducke Reserve have been increasingly affected by the continuous urbanisation of Manaus. Although this protected forest reserve, it has been deforested the outskirts, in particular, the eastern side where the reserve matches up with continuous forest has undergone mass fragmentation. This will result in the isolation of the reserve making it become an urban park which will have less protection and eventually become deforested. People entering the reserve are not only hunting mammal species but are extracting natural resources. I observed a hunter extract all the fruit from one tree which was regularly frequented by *S. apella*.

The new Government may implement further policies that increase deforestation in this region which could be detrimental to the future of this reserve. The current planned policy change is targeted at the forest in the state of Para with no known large infrastructure development planned for the state of Amazonas.

This reserve has a large density of primates and to ensure populations in this area remain stable, I would recommend that protection should be given to the forest on the eastern side of the reserve to create a corridor to prevent it becoming isolated from the continuous forest. This will ensure species can move freely into the connected forest to reach food sources safely without having to move terrestrially as this will open up the primates to further predation from domestic dogs and hunting activities. I suggest that patrols could be run through the outskirts of the reserve to deter hunting activity. However, this would cost money and could lead to violence as hunters are usually armed. Funding for these patrols would be difficult to get as funding has for institutions and protected areas has been reduced in recent years. Also, although research presence usually deters hunting activities, this doesn't seem to be the case at RFAD. This reserve is a heavily studied reserve and hunters and signs of hunting activity were frequently seen suggesting that hunters do not care if they are detected. This may be partly due to the fact that although hunting is illegal it is not enforced by federal police and the government.

In conclusion, this study has provided insight into the current primate density and conservation status at a Ducke Reserve in Central Amazonas. It has shown that this reserve has a large density of primates despite being in close proximity to a large urban metropolis. Density estimates are similar to those found in Rodriues and Vidal, (2011) and TEAM (2006), suggesting that even though human activity is rife at RFAD, it has yet to affect the primates. Further studies are required to 1) continue monitoring primates at RFAD to assess how urban areas affect primate populations; 2) monitor forest loss and urban planning around the reserve to ensure unnecessary development is avoided; and 3) monitor the Golden Handed Tamarins range expansion in the region of Manaus.

Chapter 2: Use of arboreal cameras to assess primates at Reserve Adolpho Ducke and guidelines on how cameras can be used arboreally in tropical forests

6. Introduction

6.1 Camera trap history

Technologies in wildlife monitoring have developed to indirectly monitor populations throughout a variety of habitats, especially tropical forests (Galvis, Link and Di Fiore, 2014), and are a standard tool in population studies of wildlife (Olson et al., 2012). Camera traps have been used in wildlife monitoring since the 20th century and are becoming increasingly common (Rowcliffe and Carbone, 2008). One of the preliminary studies using camera trap technology was to estimate tiger abundance in Nagarahole National Park (O'Connell, Nichols and Karanth, 2011). Camera traps have since been successfully used in many important frontiers which have revolutionised the field of wildlife biology ranging from new species discovery (Rovero et al., 2008), estimating abundance (Thinley et al., 2015) and monitoring behaviour (Glen, Cockburn, Nichols, Ecanayake and Warburton, 2013).

Many scientific research projects have adopted camera trap technology to gain access to isolated wildlife populations and habitats. They allow researchers to effectively study and monitor populations without the use of physical capture or direct observation (Tan, Yang, and Niu, 2012). Camera traps have revolutionised the study of medium/large terrestrial species (Di Cerbo and Biancardi, 2012), with species being recorded that have never been observed during line transect surveys (Tobler et al., 2008). Before this method was developed, distance sampling was the commonly used method when estimating abundance and density of terrestrial and arboreal species. Visual observations are also the primary method when studying group dynamics, behaviour, life history traits and ecological studies. However, distance sampling comes with many issues; failure to record rare, elusive and cryptic species; successfully following all assumptions and working in harsh and difficult habitats.

Camera traps offer an appropriate and advantageous technique for monitoring wild populations by overcoming most of the issues created from ground-based surveys. The reasons are as follows:

1) Cost effective: Camera traps initially have a higher cost due to having to purchase equipment and installing cameras within the canopy (Whitworth et al., 2016). However, the cameras run 24hrs a day until batteries deplete which allow researchers only to return to change batteries and memory cards. Therefore after the study period, they are overall more beneficial. Recently, the cost of cameras has decreased, and they have become more available. Also, the quality of images and videos they generate is increasing (Tobler et al., 2008), making them accessible to more studies.

2) Non-invasive: Camera traps promote the studying of animals in a non-invasive manner (Bezerra et al., 2014). This is beneficial in areas which are difficult to reach, monitoring nocturnal species and detecting cryptic species that are difficult to detect from ground-based surveys. However, there have been studies highlighting the vulnerability of nocturnal species to the flash on the camera, and as a result of these species actively avoid these areas (Schipper, 2007).

3) Camera traps are a low effort investment method when collecting ecological data for terrestrial species (Gregory et al., 2014). This has yet to be tested in arboreal environments.

4) Collect bonus data: Cameras can record previously unseen behaviours which can contribute to conservation efforts and new study questions. Studies have gained information on nocturnal primate activity and chimpanzee cave activity (Boyer-Ontl and Pruetz, 2014).

5) Images can be used in conservation and education projects to induce interest in students, children and investors (Boyer-Ontl and Pruetz, 2014). It is a more engaging and interactive way of capturing the attention of the public.

As camera traps have had tremendous success in terrestrial environments, it would be logical to assume that this method would be successful when deployed in the canopy (Whitworth et al., 2016). Specially because half of the world's biodiversity is found in the canopy of rainforests (Azadeh, Dimitrios and Peter, 2017), and arboreal species also possess a crucial role in rainforest generation, seed dispersal, pollinators, and forest diversity. Nevertheless, research in this area is scarce, and knowledge of arboreal rainforest species is inadequate. This has occurred due to arboreal mammals being highly elusive, difficult to monitor and many species are nocturnal (Gregory et al., 2014) creating an urgent need to increase our understanding of tropical arboreal species (Whitworth et al., 2016 and Bezerra et al., 2014).

Camera trap technology has taken the discovery of the biodiversity of arboreal species to new heights. Although arboreal camera traps are still generally uncommon, they are becoming more accessible due to improved climbing techniques, sampling designs, and camera technology. This technology is providing new insight into life and diversity in tropical forest canopy which is enabling scientists to discover tropical forest species from a new angle.

Although canopy camera traps have been used in other South American countries (Whitworth et al., 2016 and Gregory et al., 2014) and one documented paper in Madagascar (Olsen et al., 2012), there are few studies from the Brazilian Amazon. One study developed in the Cuieiras Reserve, Manaus, Central Amazonia (Arévalo-Sandi et al., 2018), showed differences in mammal composition and richness among vertical strata using camera traps.

6.2 Using cameras to study primates

Decades of dedicated observational primate studies have provided researchers with all known facts about many aspects of primatology (Boyer-Ontl and Pruetz, 2014). However, long term monitoring is expensive (Whitworth et al., 2016), time and cost consuming and can cause the spread of disease (Boyer-Ontl and Pruetz, 2014). Also, primates can be challenging to study ex-situ due to complex habitat structure, cryptic behavior and group living (Gerber, Williams and Bailey, 2014). Many land-based studies have habituated primates to collect direct and close-range observational data (Bezerra et al., 2014). However, although habituating primates has incredible strengths (Boyer-Ontl and Pruetz, 2014), it can also be a difficult and lengthy process (Bezerra et al., 2014) which can cause risk to species in areas with hunting pressure, and deforestation.

Amazonian primates are primarily arboreal and can be difficult to detect from terrestrial studies due to their cryptic nature and dense vegetation (Gregory et al., 2014). Certain Neotropical primates including *Chiropotes* and *Pithecia* species have been known to avoid areas of human presence making studies on them difficult (Gadelha et al., 2017). Small primates such as *Saguinus* can also be difficult to study in-situ due to how small they are, access to rural habitats and the dense vegetation of the Amazon.

In recent years, primatologists have begun to take advantage of the benefits camera traps can have by using this method to obtain data on cryptic species, activity patterns (Tan, Yang and Niu, 2012), monitoring natural behaviours and corridors (Gregory et al., 2014) preliminary studies on newly discovered species (Chen et al., 2015), geophagy (Blake et al., 2010), reproduction and predator frequency (Bolt et al., 2015) among others. Boyer-Ontl and Pruetz, 2014 used terrestrial camera traps to study unhabituated chimpanzees, comparing how successful the camera trap method is to visual observations. This study found that camera trap footage corroborate and complement visual observations.

Current studies using cameras to study primates have only situated cameras at low heights (an average of 10 m) usually using feeding platforms. One such study assessed non-habituated blonde capuchins life history and behavioural ecology (Bezerra et al., 2014) used “bait” to lure primates to the cameras. “Arboreal” cameras placed up to 10m off the forest floor have not truly represented primates in the canopy; it is recommended that cameras should be deployed at 15-20m to represent canopy diversity (Whitworth et al., 2016).

Few studies have utilised the tops of the canopy in the Neotropics. Whitworth et al., (2016) presented research resulting from camera traps situated in the canopy in Costa Rica. This research resulted in successfully creating inventories for a Costa Rican rainforest, recording undocumented species and improving camera trap sampling methods. Other research in the Neotropics has focused on spider monkeys. Spider monkeys are a difficult species to study as they live in the highest areas of the canopy making it difficult to view all aspects of their life. Furthermore, arboreal cameras have not been reported to have been used in the Brazilian Amazon to survey primates, including RFAD, making this the first study of its kind.

6.3 Aims and Objectives

The main aims and objectives of this study were: (1) test the effectiveness of camera traps in surveying primates in the canopy of a tropical rainforest; (2) also test the effectiveness of camera traps in surveying other arboreal fauna; and (3) learn what should be avoided for these studies to be more successful in the future.

7 Method

7.1 Camera set up and data collection

I began investigating how primates are studied using cameras at RFAD on January 2018 and completed data collection in January 2019. Camera traps were placed at around 10 to 20 m high on trees throughout Reserve Ducke (Table 6), with the help from two specialist tree climbers to correctly and safely assemble the traps. Eleven camera traps were placed in suitable tree trunks facing branches (this includes large secure branches that can support primates and had fewer branches and trees blocking the camera's view). Many aspects were considered before placing cameras in the canopy including the amount of vegetation and areas in which primates can move. The cameras were secured with a strap, ensuring that they were secured around the tree. GPS points were taken for all the cameras (Trees were marked with orange flagging tape which was marked with the camera number abbreviated to CT 1 – 11, making it easier to find the cameras without alerting unwanted attention.

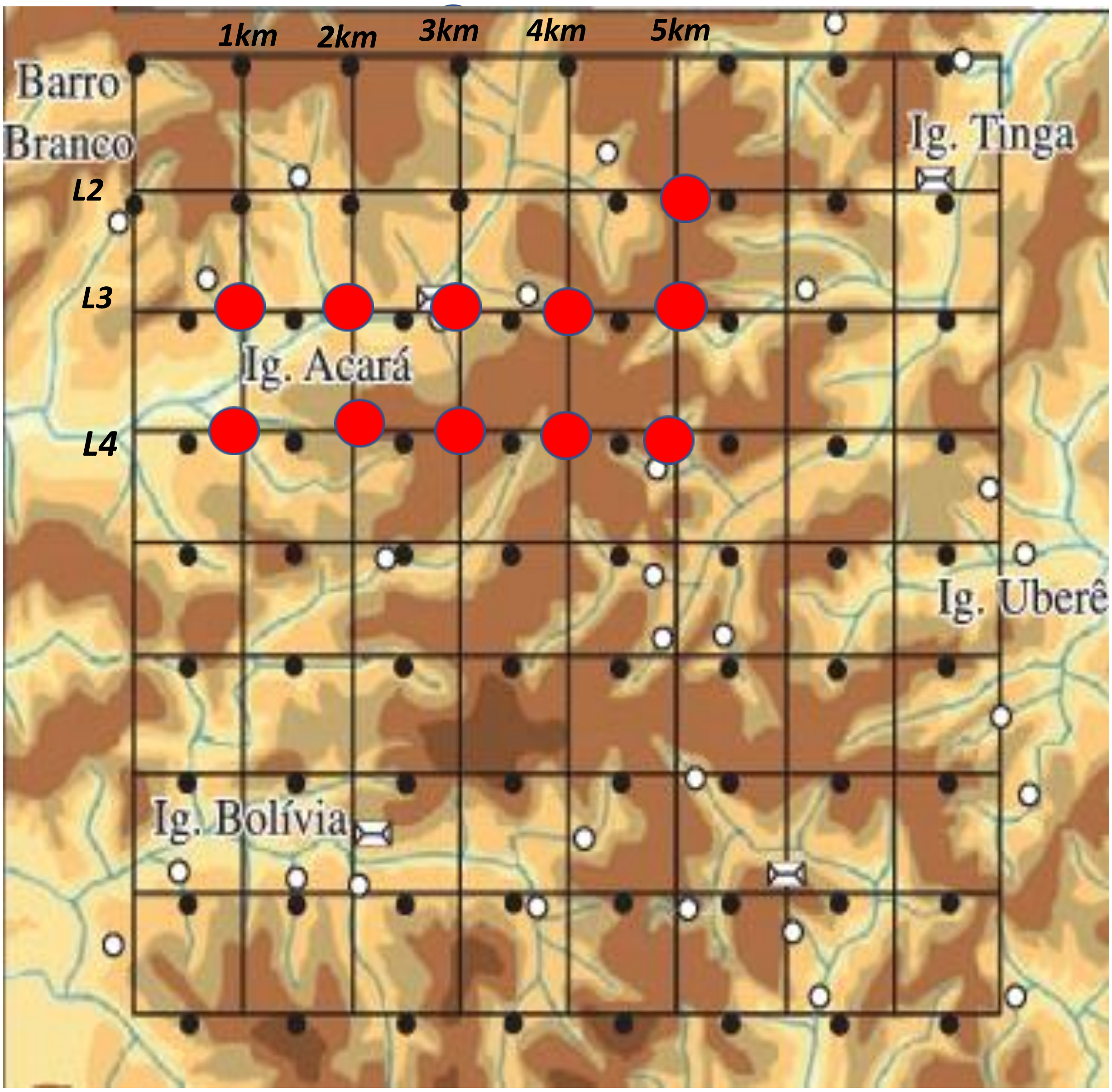


Figure 14: Camera trap placement at RFAD. L3: Camera's 1 – 5 with 1 camera at 1km and camera 5 at 5km. L4 Cameras 7 -11 with 7 at 1km and 11 at 5km. The only camera on L2 is camera 6 at 5km.

Figure 15: Bushnell HD nature view camera used in this study.

This study used 11 Bushnell nature view cameras (Figure 15), and they were placed along three transects in the reserve (figure 14). Five were placed on transect L3/4, (1km-5km) and one was placed on L2 at (5km) with all cameras placed 1km apart at various heights ranging from 11.4 - 18m (table 6). The cameras were positioned at every kilometre, with no further than 15m from the trail intersections, in every direction. All cameras were set to record one photo and one 15 second video and were constantly recording 24 hours per day and triggered via a motion detector. Motion detectors picked up any movement in front of the cameras up to 20m away. Camera trap batteries and SD cards were replaced on April the 25th-27th 2018 with one tree climbing specialist. Two of the cameras had water damage but still worked. These cameras were taken back to camp to be fixed and dehumidified and were put back out with the other cameras. All batteries and SD cards were replaced. Finally, the cameras were removed from the canopy in January 2019 by one tree climbing field assistant.

Table 6. Camera trap locations, heights and elevation at Reserve Adolpho Ducke.

Camera Number	Heights (m)	Elevation (m)	Location
1	18	51	L3 – 1km
2	15.2	65	L3 – 2km
3	16.6	26	L3 – 3km
4	17	80	L3 – 4km
5	13.2	113	L3 – 5km
6	11.4	125	L2 - 5km
7	8	64	L4 – 1km
8	16.2	115	L4 – 2km
9	14	128	L4 – 3km
10	13.1	131	L4 – 4km
11	17	137	L4 – 5km

7.2 Data analysis

To analyse the images, I first watched and removed all unwanted images including false triggers, i.e., moving vegetation, extreme weather and blinding sunlight images. I then saved the images in separate files according to which camera the footage was taken from. Individuals were identified using windows photo viewer, personal knowledge and researchers at INPA. Not enough data on primates is available at this reserve to identify specific individuals.

Following other studies, sightings on camera trap footage were considered separate events after 30min apart.

8 Results

This study used footage from January 2018 – April 2018 (91 days). The rest of the footage was unable to be used due to malfunctions on the external hard drive. During the 91 day period 11 camera traps captured images of primates, birds, nocturnal mammals and false triggers. A total of 11,643 images were captured in the 91 days the cameras were assembled. 261 of these files had images and videos of detections leading to 11,382 false triggers. Four cameras did not detect any animals (Camera 3, 4, 7 and 8).

This study detected five of six species of primates present in this area of the reserve throughout the 90 days the cameras were assembled in the canopy. *S. apella* were the most common primate species and were captured 19 times (Figure 16). The least common species was *A. macconnelli*, and *S. bicolor* only captured twice on the same camera (table 7). *A. macconnelli* stayed in front of the camera for an extended period and were viewed eating, using their tails to groom their backs and using their prehensile tail to hold on to the branch to reach a food source. In the first period of study, *Pithecia chrysocephala* was not captured in the first camera trap deployment but were detected in the second set of footage. Images of *P. chrysocephala* were saved separately before all footage was lost. *P. chrysocephala* was observed in unusual group composition with two adult males together (Figure 18). Additional data of 4 bird species were detected with two other species identified by vocalisation and only one nocturnal mammal was detected *Potos flavus* more commonly known as the Kinkajou (table 7) and was detected in 19 separate sightings.

Table 7. Canopy species inventory. Number of detections were separate events after 30 minutes. Diurnal = D and Nocturnal = N.

Common name	Species Name	Number of Detections	Diurnal or nocturnal	IUCN status
Northern Bearded Saki	*Chiropotes sagulatus*	11	D	Least Concern
Barefaced tamarin	*Saguinus bicolor*	2	D	Endangered
Brown capuchin	*Sapajus apella*	19	D	Least Concern
Golden-faced Saki	*Pithecia chrysocephala*	1	D	Least Concern
Guyana Red Howler	*Alouatta macconnelli*	2	D	Least Concern
Kinkajou	*Potos flavus*	19	N	Least Concern
Ingrid Squirrel	*Sciurus aestuans*	2	D/N	Least Concern
Guianan Toucanet	*Selenidera piperivora*	1	D	Least Concern
White-throated Toucan	*Ramphastos tucanus*	1	D	Vulnerable
Male Black Tailed Trogon	*Trogon melanurus*	1	D	Least Concern

Figure 16. A selection of capuchins *(S. apella)* images taken from the camera traps.

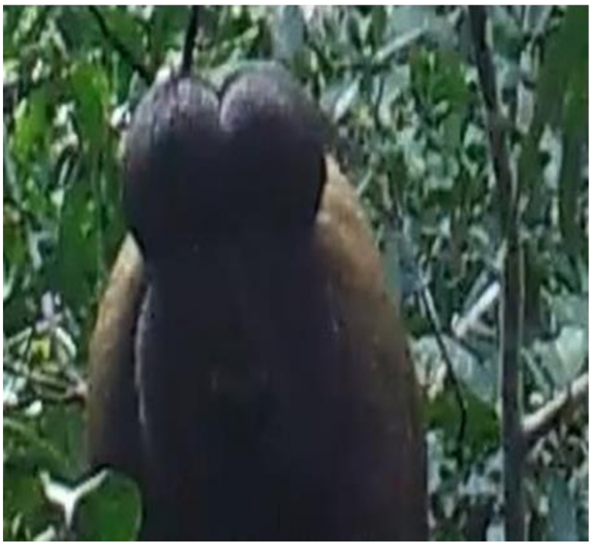


Figure 17 Two images of *S. bicolor;* B) Two images of *A. macconnelli* resting and feeding using prehensile tail to reach food; C) Image of *C. sagulatus* looking at the camera

Figure 18. Two images of *P. chrysocephala* found on the cameras at Reserve Ducke. A) Two adult males and a female; B) One adult male.

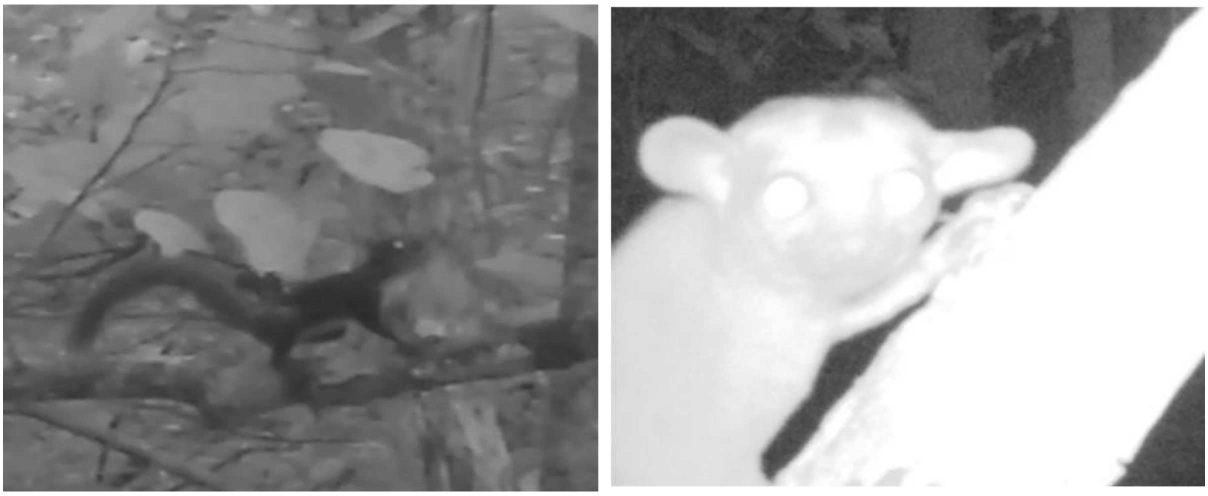


Figure 19. Nocturnal images taken on the cameras including A) Ingrams squirrel *Sciurus ingrami* and B) kinkajou *Potos flavus*.

8.1 Camera Malfunctions and damage

Cameras in this study had many issues over the period they were in the canopy at Reserve Adolpho Ducke. These malfunctions occurred for a number of reasons including full memory cards, dead batteries, water damage, robbery, false images, and wrong placement. During the first three months cameras run for 91 days. This resulted in two cameras having water damage but were still functioning when recovered. As a precaution, they were taken back to camp to be dried out and dehumidified and were later redeployed in the same position. After the cameras were changed they were deployed back in the canopy for a further nine months without been checked. During these nine-months, 4 of the cameras malfunctioned, and one was missing resulting in only 6 working cameras. All problems that this study faced were analysed and solutions were proposed (Table 8).

Table 8. Proposed solutions for the problems this study underwent.

Problem	Result	Solution
The sun on cameras	Images ineligible to view due to the glare of the sun	Placing the cameras, so they never face the sun to avoid having glare on images making them illegible. Avoid open areas with lots of sun exposure
Tagging on trees	Hunting – Making people aware of the camera's presence and people stealing the cameras	Find ways to mark the trees to avoid other people noticing them. Use more secure fastenings including bolts and mounts for the cameras. Could secure with padlocks Tracers could also be put on cameras to further deter people from taking them, although this would be expensive
Water Damage	Cameras ended up broken after been in the canopy for an extended period.	Check the cameras frequently to maintain the cameras. To stop condensation silica packages could be put in the cameras. This would be easier to do on dry days.
False Triggers – Wind and leaves	Produces a mass of photographs and footage of just moving vegetation	Remove as many branches as possible from the view of the camera. Use a large trunk or branch that will not move or sway due to the wind.
Battery life	Dead batteries caused for less footage to be recorded	Frequently checking and changing camera batteries. Batteries In this project lasted over five months. But many cameras ended up damaged, so regular checks are required.
Propper set up/ camera placement	Cameras are not recording any footage. Cameras picking up unnecessary footage	Make sure cameras are on the correct settings and have had the batteries and SD cards inserted correctly before deploying in the canopy. Utilise the view checker device to check the view from the camera.
Not capturing the full animal	Difficult to identify due to only viewing part of the animal or only seeing the moving vegetation afterwards	Place cameras in positions where they can follow the direction of the branch leaving as much room as possible to record the animal.

9. Discussion

I found that arboreal cameras are a unique and exciting way of surveying primates in the canopy and if cameras are appropriately used, they can study primates with minimal challenges and effort.

Previous line transect sampling studies carried out by observers on the ground detected five of six primate species, two-toed sloths, squirrels and other terrestrial species that also can use the canopy including the Coati and Collared lesser ant-eater (Oliviera et al., 2008). Though the majority of these arboreal mammals were not recorded on the cameras, it does not mean they are not present at the reserve.

This study found that camera trapping corroborated data collected using line transects. Specifically that *S. apella* was the most abundant species as it was observed the most on the cameras and in during the line transect studies. The images/footage from the cameras cannot however truly represent group size as only a few individuals were seen on each image. Although, behaviours and interactions between individuals, foraging behaviour and vocalisations were recorded which could later also be added to a larger database.

Potos flavus was documented multiple time on the arboreal cameras but has never been recorded during terrestrial diurnal surveys. This species is very cryptic resulting in it being understudied with very little knowledge about the species throughout its large range. Kinkajous in this study were seen on numerous cameras throughout the study site and were seen numerous times on the same camera a few days after first appearing going in the opposite direction. Individuals were seen interacting with the cameras and looking inquisitive while the cameras were recording. Kinkajous have also been known to avoid camera traps due to their sensitivity to the flash from cameras (Schipper, 2007), but this study repeatedly saw individuals on the same cameras moving in opposite directions. To be more cautious, alternative cameras with a less bright flash or inferred light should be used when considering studying nocturnal mammals.

Many methods can be used to put cameras up in the canopy with many choosing professional tree climbing equipment. This study chose to use a local guide who was comfortable and experienced climbing trees without industrial climbing equipment making the cost for establishing the camera traps low. However, it has been recommended in studies that a professional climber should be used to ensure health and safety (Whitworth et al., 2016). Also, it may also be more suitable to ensure that cameras are placed in the correct position to fulfil the maximum potential to capture arboreal species.

The arboreal camera traps were able to achieve and produce large amounts of data in a short period of time. The camera traps were effective in identifying all primate species at the reserve. As all but one species was detected in the first 90 days, it gives great optimism that cameras would be beneficial in monitoring primates in arboreal tropical environments.

Camera traps are not accessible to all studies due to the initial expense of purchasing multiple cameras but the overall costs using this method are lower than that of a long-term monitoring program using traditional terrestrial methods to study the canopy (Whitworth et al., 2016). Camera traps requires little effort, maintenance and is generally less invasive and in the long term a greater investment. Cameras also provide the opportunity for researchers to find new information on species (Deng and Zhou, 2016) including fruit or seed consumption and unexplained behaviour made by cryptic species (Mcphee, 2003).

As this was the first time I had used cameras in the canopy the inexperience led to not capturing as many species as other studies have. A pilot study was carried out in the Cuieiras reserve near Manaus using 9 cameras and recorded 15 mammal species in 60 days. Now I have a better understanding of how cameras work and how they can be assembled, more detections should occur on the cameras. In addition, the camera model was not very successful. Understandably, many of the Bushnell nature view cameras suffered water damage. Other studies using cameras in the canopy use Reconyx cameras which are more equipped for harsh environments but are far more expensive.

In conclusion, for follow up studies we suggest including more cameras throughout different areas in the reserve, cameras at different stratums in the forest and narrowing down research questions in which the cameras could address. A better quality camera model such as Reconyx should be used to avoid unnecessary damage and to be cost effective. Camera traps should be an essential tool used in arboreal tropical forests to maximise our knowledge of this unknown habitat.

9.2 Future for Arboreal cameras

Camera trap technology is continuously developing with strides been taken in longer battery life, improved methodology and analysis and better image quality. The main issue to address with canopy camera traps is the amount of false images produced by the dense vegetation in the canopy. A study by Gregory et al, (2014) resulted in 98% of camera footage being generated by false triggers. New software's such as camerbase and wild.id are been produced to analyse data quickly and efficiently.

10. Supplementary materials

How to upload data to distance

1) **Survey methods and measurement units:** Open distance 7.0 software and create a new project file. Once the project setup wizard appears, select “analyse a project that has already been completed”. This option allows data to be imported in the software if it has been organised in excel to work in distance. Line transects were sampled by a single observer with perpendicular measurements made to clusters of objects and was selected in this section with meters selected for the transect and distance option and square kilometre for the area (Figure 20).

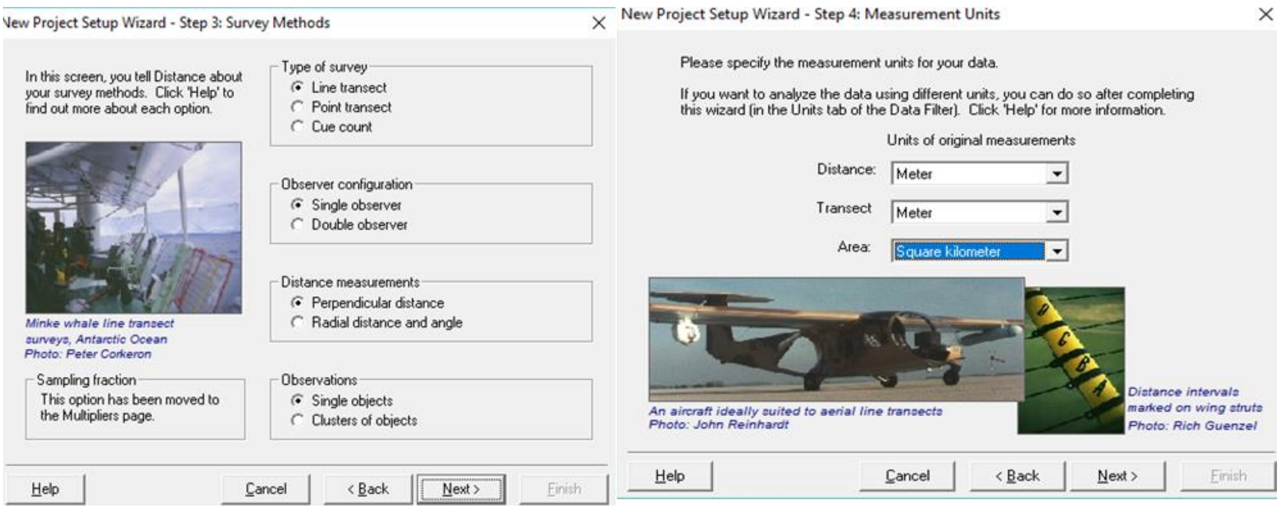


Figure 20. Screenshots from Distance software of A) Selecting set survey methods my study followed and B) measurements I have used.

2) **File format:** Data was organised in excel and saved as a text delimited file. Only text delimited files can be uploaded onto distance. Data was uploaded separately for each species by repeating each one of these steps. Delimiters were selected so ensure columns are separated so data is recognised and read correctly by the

software. The first row is selected to not be imported as distance already provides this. The decimal symbol "." was selected to distance knew how to recognise the measurements.

3) **Data file structure**: The next step was to make sure the text delimited file was correctly imputed and could be read by distance. The box "columns are in the same order as they will appear in the data sheet" should be selected. This allows a shortcut putting the correct layer name, field name and field type to the already organised data (Figure 21).

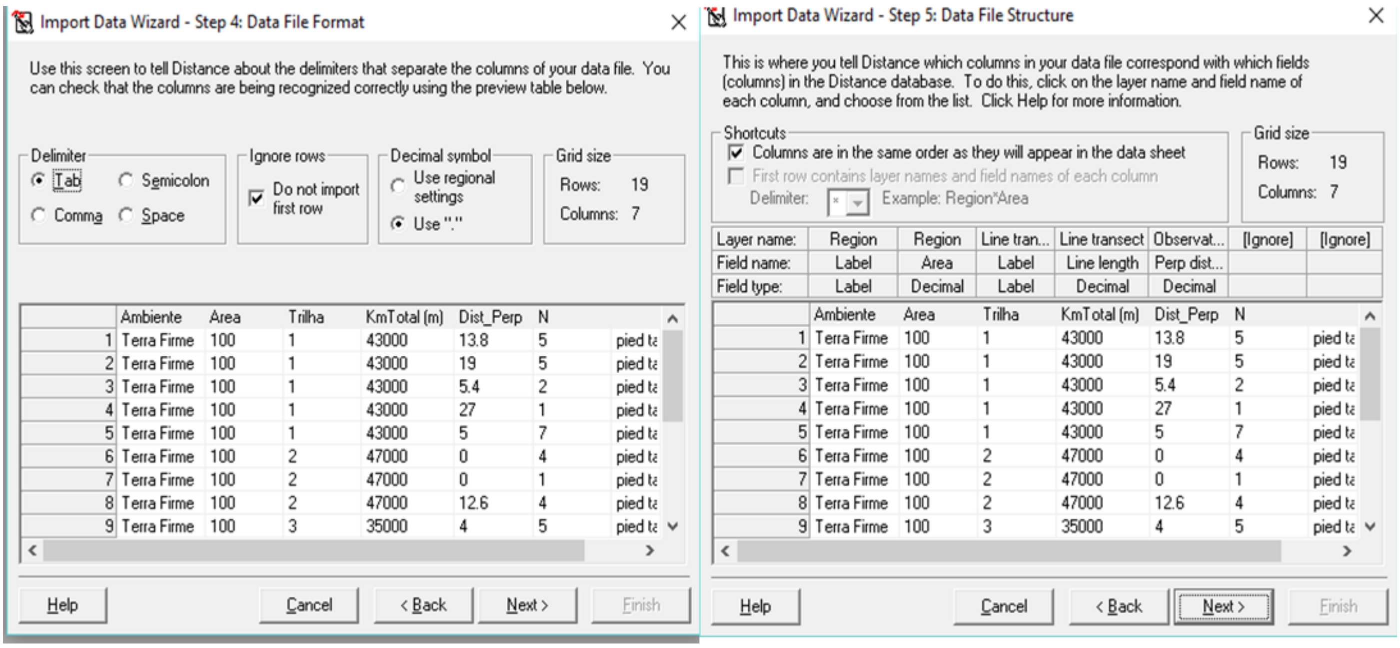
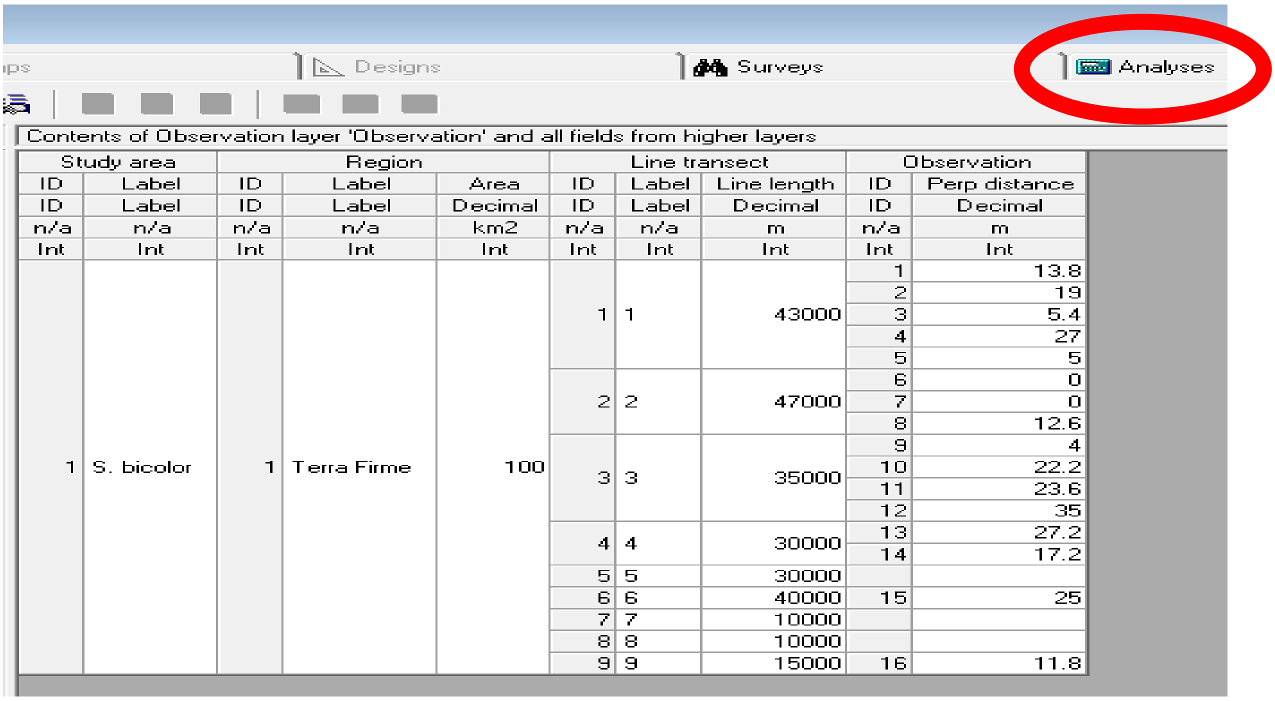


Figure 21: Screenshots of A) File data format and B) File data structure.

4)**Finished layout of Data:** Once the previous step is done, press finish. This produces Figure 22. This is when you can double check all data is correctly placed before analysing any data. Once this is all checked, proceed to analysis which is circled in red (Figure 22)



Study area		Region			Line transect			Observation	
ID	Label	ID	Label	Area	ID	Label	Line length	ID	Perp distance
ID	Label	ID	Label	Decimal	ID	Label	Decimal	ID	Decimal
n/a	n/a	n/a	n/a	km2	n/a	n/a	m	n/a	m
Int	Int	Int	Int	Int	Int	Int	Int	Int	Int
1	S. bicolor	1	Terra Firme	100	1	1	43000	1	13.8
								2	19
								3	5.4
								4	27
								5	5
					2	2	47000	6	0
								7	0
								8	12.6
					3	3	35000	9	4
								10	22.2
								11	23.6
								12	35
					4	4	30000	13	27.2
								14	17.2
					5	5	30000		
					6	6	40000	15	25
					7	7	10000		
					8	8	10000		
					9	9	15000	16	11.8

Figure 22. This screenshot shows what your data should look like once up loaded to distance. The analysis button is the next step and is circled in red.

5) **Analyse data:** Select create new analysis. This allows a default run of the data through distance. Defaults used a Half normal with a cosine adjustment for all species. This is the first trial to model the detection function based on my data. From I could then investigate if any truncations or adjustments would be needed for a better fit (Figure

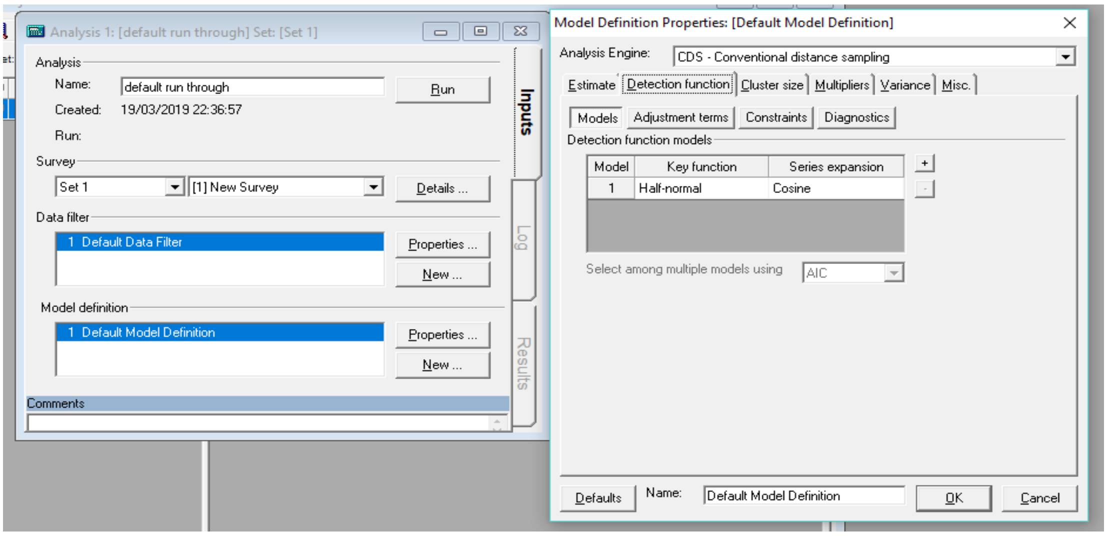


Figure 23: Default run through of data using half normal cosine

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